Uniformed Services University of the Health Sciences

Manuscript/Presentation Approval or Clearance

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5. Type of clearance: __Paper __Article __ Book ___Poster ___Presentation_X_Thesis

6. Title: Incidence and Characterization of Asymmetries of the Mandible Using CBCT Technology

7. Intended publication/meeting: Requirement for Masters in Oral Biology

8. "Required by" date: 01Jul15

9. Date of submission for USU approval: 10Jul15

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External Affairs Approval Date

POST-RETENTION CHANGES IN CLASS II CORRECTION WITH THE FORSUS™ APPLIANCE

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Uniformed Services University
10 July 2015

Post-Retention Changes in Class II Correction With the Forsus™ Appliance

A THESIS

Presented to the Faculty of the

Tri-Service Orthodontic Residency Program

In Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Min K Kim, DMD

San Antonio, Texas

June 1, 2015

POST-RETENTION CHANGES IN CLASS II CORRECTION WITH THE FORSUS^{TM} APPLIANCE

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ACKNOWLEDGEMENTS

I would like to thank Dr. Curtis Marsh for his mentorship and patience throughout this arduous process. His unceasing guidance was invaluable in completing this project. I would also like to thank Dr. Lisa Alvetro for providing all of the radiographs for this study. Lastly, thank you to Mr. Danny Sharon for providing statistical support.

DEDICATION

First and foremost, I would like to thank my Lord and Savior Jesus Christ for showing me the way in this residency and in life. Secondly, I am forever grateful to my family for their continual support and reassurance in completing this residency. Dad and Mom, I could not have done this without you.

ABSTRACT

Introduction: The goal of this retrospective, descriptive study was to evaluate post-treatment changes of non-extraction treatment of class II correction using the Forsus^{TM} appliance. **Methods**: 40 Class II patients (25 males, 15 females) consecutively treated with the Forsus^{TM} appliance had cephalometric radiographs taken before treatment, at the end of comprehensive fixed and Forsus^{TM} treatment, and 1-4.5 years out of retention. Each radiograph was digitally traced by one examiner and intrarater reliability was measured. 29 cephalometric variables (angular and linear) were analyzed. **Results**: At debond to post-retention, SNA and SNB increased 0.9±1.9 degrees and 1.0±1.3 degrees respectively, IMPA increased 1.6±4.0 degrees while overjet and overbite decreased 0.8±0.7mm and 0.9±1.0mm respectively. **Conclusion**: The null hypothesis was rejected. The increases seen in SNA and SNB during the post-retention period were most likely due to continued normal growth.

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I. BACKGROUND

A. Class II malocclusion

Malocclusion is defined as an improper alignment of teeth or an inappropriate relationship between the maxillary and mandibular arches. The etiology of malocclusion is threefold: specific, hereditary, and environmental and oftentimes, malocclusions arise due to a complex interaction between these factors.[1] Edward Angle, oft considered the "father of modern orthodontics" and credited with formulating the concept of occlusion, created four classes of malocclusion—Normal occlusion, Class I malocclusion, Class II malocclusion, and Class III malocclusion. In a Class II malocclusion, the lower molar is distally positioned relative to the upper molar; more specifically, the mesiobuccal cusp of the maxillary first molar is mesial to the mesiobuccal groove of the mandibular first molar. Class II malocclusions account for approximately 33% of the malocclusions seen in the population with Caucasian populations of northern European descent having the most prevalence.[2]

A class II patient exhibits a variety of characteristics that have both a dental and skeletal component. Dentally, patients can have excessively proclined incisors and increased overjet (Class II Div 1) or excessively retroclined incisors and a deepbite (Class II Div 2). Skeletally, patients can have a prognathic maxilla or a retrognathic mandible, or a combination of both. The most common characteristic was found to be a retrognathic mandible with excessive vertical development.[3] Other common features of a Class II

malocclusion can include a convex profile, retrusive lower lip, clockwise rotation of the mandible, and poor chin projection, or retrogenia.

B. **Class II Malocclusion Treatment**

Many treatments have been used to correct Class II malocclusions to include removable or fixed functional appliances, orthognathic surgery, orthodontic camouflage, or selective extraction patterns.[4,5,6,7] Two of the most commonly used treatments are "maxillary distalization" and "mandibular enhancement" mechanics.[8] Maxillary distalization involves correction of the Class II molar relationship by movement of the maxilla and/or the maxillary teeth with a variety of appliances to include the headgear. Studies have shown that maxillary protraction can be restricted through using this appliance,[9,10] while mandibular enhancement utilizes one's growth potential through jaw orthopedics primarily by the use of functional appliances. This changes the posture of the mandible, holding it open or open and forward. There are a plethora of studies that show Class II correction in growing patients by utilizing functional appliances.[11,12,13,14] Jones et al, 2008 noted that the appliance's ability to create greater forward displacement of the mandible was the main factor in successful Class II therapy.[4] Other means of Class II treatment include distalization of the maxillary molars,[15] mesial movement of the mandibular first molars, and retraction of the upper incisors and proclination of the lower incisors; these modalities improve the dental relationship but do not address skeletal components.[1] Lastly, Class II treatment involving control of the vertical

dimension prevents down and back rotation of the mandible, which would facilitate the amount of Class II correction required.

C. **Stability and Functional Appliances**

There are numerous studies that have revealed the effectiveness of functional appliances in correcting Class II malocclusions in growing patients.[16,17,18] Functional appliances can be fixed or removable, but due to compliance issues, bulkiness, and an unesthetic appearance, removable appliances have waned in popularity. There are many fixed functional appliances such as the Herbst, Eureka Spring, Jasper Jumper, Twin Force Bite Corrector, or Forsus™ that can be used as a part of comprehensive fixed orthodontic treatment. The proposed mode of action of these functional appliances is based on the remodeling of the condylar process and in part the Glenoid Fossa[32] in a direction that will permit mandibular lengthening. Their goal is to stimulate mandibular growth but that issue remains a hot topic of debate. In the 1970s, research on Rhesus monkeys and rats showed that skeletal changes could be produced by posturing the mandible to a new position,[19,31] which left open the possibility that mandibular growth could be altered. In a 2-phase randomized clinical trial of early Class II treatment, it was shown that accelerated mandibular growth can occur.[20] Recently, a systematic literature review of mandibular changes produced by functional appliances in Class II malocclusions concluded that about 67% of the samples in the 22 articles investigated had clinically significant supplementary elongation in total mandibular length.[14] It was also found that the amount of supplementary growth was significantly greater when

functional treatment was performed at the adolescent growth spurt.[14] Hence, it has been recommended to begin treatment with a functional appliance to coincide with the peak growth of the mandible.[33]

Maintenance of both skeletal and dental changes must be considered when looking at the stability of Class II correction. Good occlusion and intercuspation, a lack of skeletal relapse, appropriate function, and soft tissues are some of the most important factors for long term stability.[21] Other factors that may influence stability include the potential for continued growth, severity of the pretreatment malocclusion, gender, and pretreatment arch length.[22] For example, the Herbst functional appliance has been extensively studied by Pancherz, and in one of his articles, he found relapse to be caused by a persistent lip-tongue dysfunction and an unstable cuspal interdigitation after treatment.[36] More stability results for Class II correctors, be they long-term or short-term, have been investigated. In a 2 to 7 year post-retention span following Twin Force Bite Corrector treatment, stability was noted in over 90% of the patients in terms of maintaining the overjet reduction, stable Class I molar and canine relationship with coincident midlines, and soft tissue profile.[6] Another study found significant long-term mandibular changes (Condylion-Gnathion) were associated with skeletal anteroposterior improvements, overjet, and molar relationships.[35] Other studies showed short-term occlusal stability 2 to 2.5 years post-treatment with the Herbst appliance in correction of both Class II Division 1 and Division 2 malocclusions.[23,24] Similarly, treatment with an activator-headgear combination showed long-term stability of Class II correction 12-15 years out of

retention.[25] One recent study on the FR-2 functional appliance of Frankel showed that correction of Class II malocclusion was favorable over the long term relative to dentoskeletal changes.[37]

D. **Forsus Fatigue Resistant Device**

The Forsus™ Fatigue Resistant Device (FFRD) is an example of a fixed functional appliance. It fulfills many of the desired characteristics of an ideal Class II corrector to include ease of use, relative comfortability to the patient, efficient correction of Class II malocclusion and durability. According to a study where a survey was administered to 70 patients regarding the patient's experience with the FFRD, 81.5% of the respondents reported a neutral to favorable experience.[26] Many studies have shown the FFRD to be effective in correcting Class II malocclusion.[4,27,28] In addition, FFRD has been shown to work well when used in conjunction with miniscrew anchorage.[29] One specific Forsus™ study to note was that of Franchi. In this study, 32 Class II patients were consecutively treated with the FFRD in conjunction with fixed appliances and the success rate was 87.5%. A significant restraint in the anterior-posterior position of the maxilla, a significant increase in mandibular length, and a significant improvement in maxillo-mandibular sagittal skeletal relationships were achieved. Mean overjet was reduced by 5.5mm, while a mean net improvement of 3.4mm was seen in the molar relationship.[30] As presented in the previous section, stable dentoskeletal changes achieved by functional appliances other than the FFRD have been studied, but to date, no results on FFRD stability or post-retention studies have been published. The FFRD has been shown to be

effective, but the ideal appliance would be one that has been shown to maintain treatment changes for a long period of time.

This study was designed to look at the post-retention changes of the dentofacial complex in Class II correction with the FFRD when used in conjunction with fixed appliances. Due to the lack of a control group, relative stability to non-treated or otherwise treated subjects cannot be judged; nevertheless, changes that occurred post-treatment with the FFRD will be enumerated.

II. OBJECTIVES

A. Overall Objective

The goal of this descriptive, retrospective study was to evaluate the dental and skeletal post-retention changes of Class II correction using the Forsus^{TM} appliance in conjunction with fixed appliances during non-extraction treatment of Class II malocclusions.

B. Specific Hypotheses

It is hypothesized that some post-debond changes will occur following dentoskeletal Class II correction with fixed appliances in conjunction with the Forsus™ appliance.

Null Hypothesis

There will be no post-debond changes following dentoskeletal Class II correction in patients treated with fixed appliances in conjunction with the Forsus^{TM} appliance.

III. MATERIALS AND METHODS

A. Experimental Design

This retrospective, descriptive study was conducted using lateral cephalometric radiographs from a sample of 40 patients (25 boys and 15 girls) consecutively treated in the private practice of Dr. Lisa Alvetro (Alvetro Orthodontics: Sidney & Tipp City, OH) with the Forsus™ appliance. All cases were treated with no extractions of permanent teeth, were dentally either in the late mixed dentition or permanent dentition at the start of treatment, and the patients had a mean age of 12.4 years. They underwent a specific treatment protocol with preadjusted fixed appliances in combination with the Forsus™ appliance and underwent retention for a mean period of 2.2 years at which point a post-retention period cephalometric radiograph was taken.

<u>Sample Population</u>

The 40 patients (25 male, 15 female) treated with the Forsus™ in conjunction with fixed appliances for a mean period of 2.4 years presented with an initial mean age of 12.4±1.2 years, a final end of treatment mean age of 14.8±1.2 years, and a post-retention period age of 16.9±1.4 years. The majority of patients began with a Class II Div 1 malocclusion with a mean ANB of 5.5±1.9 degrees and a mean Wits appraisal of 2.1±3.1 mm. This sample population's mean overjet began at 7.1±2.1mm.

Appliance Design

The Forsus™ was attached at the maxillary first molar and onto the mandibular archwire, distal to the first premolar, which allowed for improved patient comfort, esthetics, and reduced interference.[43] The L-pin module was used on all sample patients except one (EZ module in this case) and placed on the maxillary first molar headgear tubes.

Initial alignment and leveling was completed in each patient and then the archwire sequence was progressed to either a 19x25 stainless steel or 19x25 beta titanium archwire before the Forsus™ was placed. After the Forsus™ was removed, a 17x25 Nickel Titanium archwire was placed on the mandibular arch to begin releveling. Box settling elastics were used after Forsus™ removal and occasionally, Class II elastics were used to maintain correction, as needed. Elastic chain was used throughout treatment and from the mandibular left to right canines during Forsus™ wear. Also, elastic chains were utilized for space closure as needed during detailing and finishing. Patients were retained with bonded mandibular lingual retainers using Ortho FlexTech White Gold (Reliance Inc.) from mandibular left to right canines and a maxillary Hawley was to be worn for an indefinite period of time. The mean duration of the Forsus™ appliance wear phase was 4.8±1.7 months with a minimum of 2.7 months and maximum of 10.0 months.

Cephalometric Analysis

The conventional lateral cephalograms of the 40 patients were evaluated and all were captured digitally with the teeth in maximum intercuspation on the Orthoceph OC100D (Instrumentarium, Milwaukee, WI) lateral cephalogram machine. The radiographs of the initial (T1), final after fixed appliance treatment and appliance removal (T2) and post-retention (T3) phases were obtained. The mean post-retention period was approximately 2.2 years. These radiographs were saved as JPEG files (de-identified with only a 6 digit number) and transferred to a disk and sent to the primary investigator (PI = MKK). These cephalograms were subsequently imported to the Dolphin™ Imaging and Management Solutions program to digitally trace the images. This program was used to obtain cephalometric angles and linear measurements from the anatomic landmarks and points selected, specifically to analyze the skeletal and dentoalveolar changes. Since conventional lateral cephalometric radiographs exhibit overlap of bilateral structures or landmarks such as the posterior dentition, condyles, zygomatic ridges, porions, or both orbitales, for consistency, all resulting lines were bisected. Furthermore, in order to allow for the same calibration for all sets of radiographs for each subject, the same millimetric ruler values were used for each time period when tracing the radiographs.

All lateral cephalometric radiographs were digitized by the PI at various sittings and 25 of the 40 sets of radiographs were retraced and remeasured after a 1 week interval by the same investigator. The customized

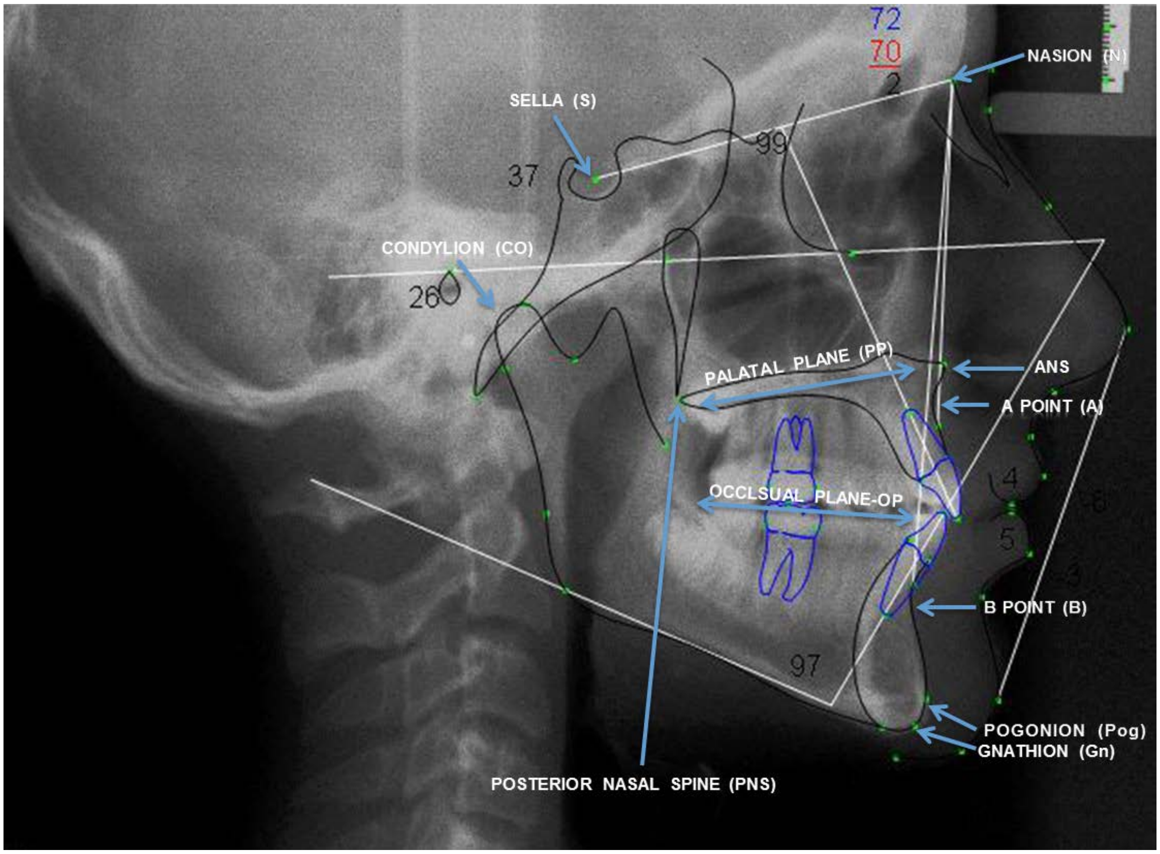
Tri-Service Orthodontic Residency Program “CEPH 2012” cephalometric analysis was used. It contains measurements from the analyses of Steiner, Jacobson, Ricketts, and McNamara, and 34 measurements were generated (11 angular, 18 linear, and 5 ratios) for each tracing. Each of these measurements fell into the skeletal and dental anteroposterior components, skeletal and dental vertical, and soft tissue components. Figures 1-3 include the significant categories and the points/landmarks used to obtain the relevant measurements. Due to some of the variables not contributing heavily to the analysis of specific post-retention changes, only 29 of the 34 variables were examined. Highlighted here are a few of those measurements: SNA, SNB, ANB, A-N⊥, Pog-N⊥, Wits, SN-GoGn, U1-SN, U1-PP, U1-NA, L1-NB, IMPA, FMA, Overjet, Overbite, G-Sn-Po, Upper Lip-S Line, and Lower Lip-S Line. A single angular or linear value was obtained for all 29 variables at each time period for each patient that was included in this study in addition to the 25 sets of retraced radiographs to identify intraexaminer error. These cephalometric measurements were then populated into a Microsoft Excel™ spreadsheet according to their respective components (i.e. Maxillary, Mandibular, Maxillomandibular Relationship, Vertical and Horizontal, Maxillary Dentoalveolar, Mandibular Dentoalveolar, Dentoalveolar Relationship, and Soft Tissue Relationship) and their respective phases (i.e. T1 (pre-treatment), T2 (post-treatment), and T3 (post-retention)) for all 40 patients and sent to the statistician for various analyses that will be explained in further detail in the results section. Throughout the discussion of the results, particular attention was paid to the T2-T3 time period.

Table I below describes a few of the salient variables.

Table 1: Cephalometric Variable Descriptions

Variable	**Description**
SNA (°)	Indicates AP position of maxilla to cranial base
SNB (°)	Indicates AP position of mandible to cranial base
ANB (°)	Indicates relative position of maxilla and mandible in relation to each other
Wits (mm)	Measure of extent to which jaws are related to each other in an AP relationship
Co-Gn (mm)	Effective mandibular length
U1-SN (°)	Angular relationship of upper incisor to cranial base
U1-PP (°)	Angular relationship of upper incisor to palatal plane
U1-NA (mm)	Relates upper incisal edge to upper apical base
L1-NB (mm)	Relates AP position of lower incisor relative to mandible
IMPA (°)	Relates mandibular incisors to mandibular plane
FMA (°)	Measure for vertical growth pattern
Overjet (mm)	Horizontal distance between most prominent maxillary incisor and most retrusive lower incisor
Overbite (mm)	Linear measurement of vertical overlap of max, man incisors

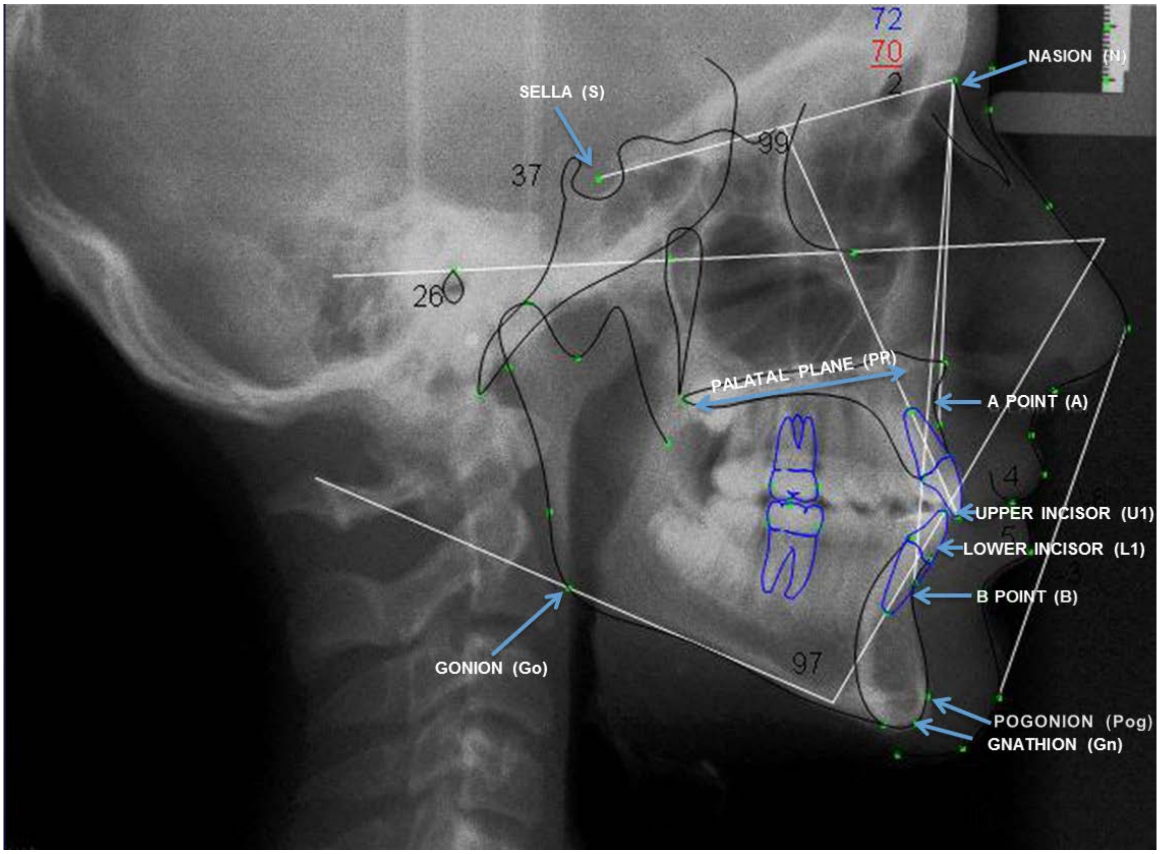
Figure 1: Points/Landmarks for Skeletal AP Measurements



<u>Skeletal AP Measurements</u>

1) SNA (deg)
2) SNB (deg)
3) ANB (deg)
4) A-N⊥ (mm)
5) B-N⊥ (mm)
6) Pog-N⊥ (mm)
7) Wits (A-OP – B-OP)(mm)
8) Max Unit Length (Co-ANS)(mm)
9) Man Unit Length (Co-Gn)(mm)
10) Max/Md Differential (Co-Gn – Co-ANS)(mm)

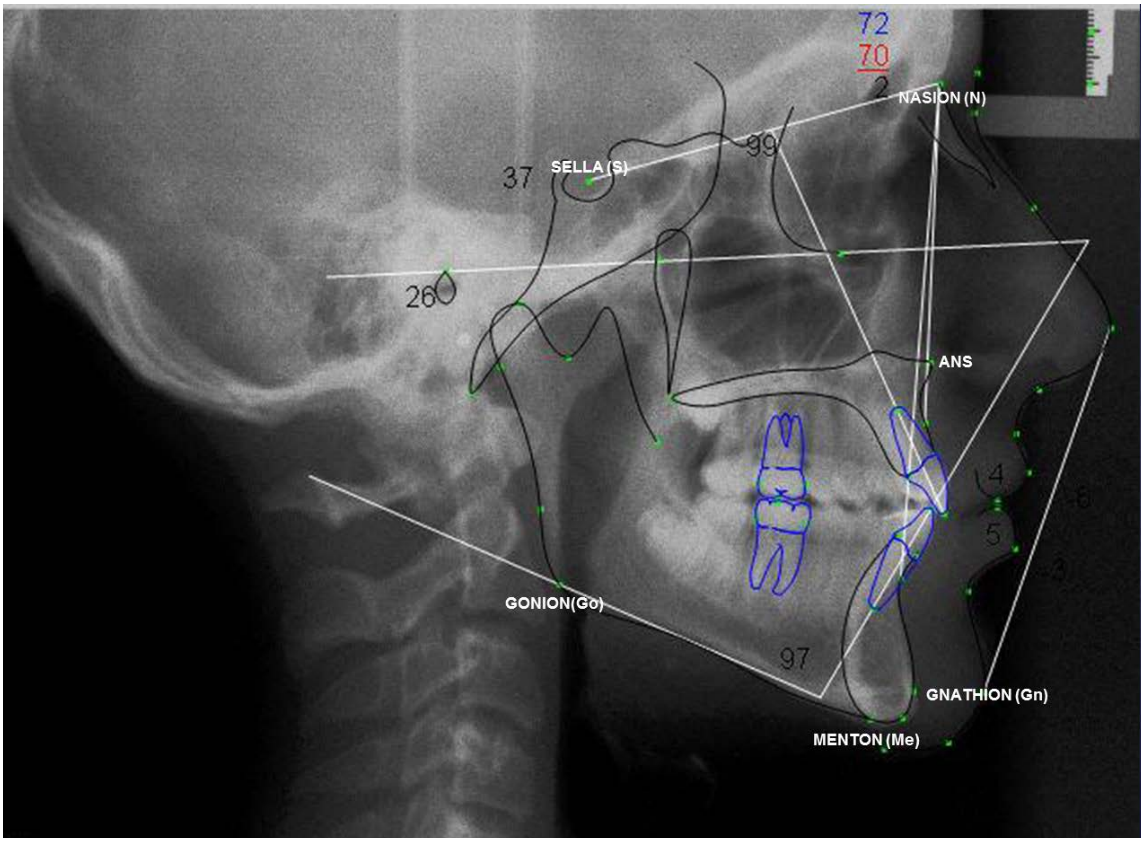
Figure 2: Points/Landmarks for Dental AP Measurements



<u>Dental AP Measurements</u>

1) U1-SN (deg)
2) U1-PP (deg)
3) L1-MP (deg)
4) U1-NA (mm)
5) L1-NB (mm)
6) Overjet (mm)

Figure 3: Points/Landmarks for Skeletal Vertical Measurements



Skeletal Vertical Measurements

1) FH-SN (deg)
2) FMA (MP-FH)(deg)
3) SN-MP (deg)
4) LFH/TFH (ANS-Me:N-Me)(%)

B. Statistical Management of Data

The sample size of 40 subjects provided the study with 80% power to detect a moderate effect size of 0.42 or approximately 0.84 standard deviation difference between means when testing with a single group paired t-test at the alpha level of 0.05 (NCSS PASS 2002).

The statistical software used to analyze the raw data was "R Version 3.0.3, R Core Team (2014)." Mean and standard deviation measurements were attained for all 29 cephalometric variables for all 40 subjects for time periods T1, T2, and T3. A repeated measures ANOVA (analysis of variance) determined if there was a significant difference among the means for the 3 time periods. Then, a Bonferroni correction post hoc test to screen for pair-wise comparisons between the time periods was applied once a significant difference was found.

The Bonferroni correction is an adjustment made to "p" values when several dependent or independent statistical tests are being performed simultaneously on a single data set. It is used to decrease the chances of obtaining false-positive results when multiple pair-wise tests are performed on a single set of data. Simply put, using this correction method allowed us to determine between which time periods the statistically significant differences were found for the various cephalometric variables. The level of significance was defined when $p \leq 0.02$.

Error of Measurement Study

In dentistry, when interpreting the results of a study, the investigator has to consider how imprecise it is to trace landmarks. In cephalometric studies,

changes may be subtle, which makes the error of the method quite important. The total measurement error arises from a combination of systematic and random error. Systematic errors (also known as “bias”) are reproducible errors resulting in a measured value that is consistently larger or smaller than the true value. Random errors result in unpredictable measurements that are greater or smaller than the true value. While systematic errors can be controlled, random errors cannot but can be decreased by averaging over a number of observations.

The Dahlberg formula has been proposed as a means of estimating the random error and assessing the reproducibility of measurements thus, evaluating the variance of error between measurements. This method assumes that the sample has a normal distribution and, mainly, there is no bias (i.e. systematic error).

25 of the 40 patients’ identification numbers were randomly selected by a random number generator program and these 25 sets of radiographs, which included T1,T2,T3 time periods, were retraced one week following completion of cephalometric tracings for all 40 patients. The author chose 25 sets because Springate[39] suggested that a sample of at least 25-30 cases should be replicated to provide a reliable estimate of the random error. This error of the method was calculated from the equation:

$$D = \sqrt{\sum_{i=1}^{N} \frac{d_i^2}{2N}}$$

where d_i is the difference between the first and the second measurement, and N is the sample size which was re-measured. As stated in Kim et al,[38] one of the

difficulties in interpreting the size of the error is that there is almost no predetermined acceptable range as it may depend on various clinical conditions. For instance, a measurement error of 1 kg may be considered with different importance when we measure body weight of an infant as opposed to an adult. Many times, researchers who have reported the Dahlberg error have concluded that “the amount of error was small enough” empirically without any further discussion. Galvao et al[40] further bolsters this assertion by stating that in several papers, “the interpretation of the result . . . is based on the personal experience of the investigator.”

Lastly, a paired t-test was carried out for the first and second measurements of all 29 variables for each time period with a level of significance established at $p \leq 0.05$. This was used to determine whether there was a statistically significant difference between the first and second mean measurements.

RESULTS:

Mean measurements for pre-treatment (T1), post-treatment (T2), and post-retention (T3) are reported in Tables 2-9 for all 29 cephalometric variables and they are divided into various components for ease of viewing. A statistical comparison of these means with a repeated measures ANOVA at a significance level of p≤0.05 revealed statistically significant different means for numerous variables which are bolded and italicized in the following tables.

Table 2- Maxillary Components

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
SNA (°)	119	81.1	3.7	40	81.4	3.8	40	80.5	4.0	39	81.2	3.8
A-Nperp (mm)	120	-2.05	3.3	40	-1.9	3.0	40	-2.4	3.5	40	-1.8	3.5
Mx Unit Length (CoANS) (mm)*	120	87.0	5.6	40	85.6	5.6	40	86.5	4.7	40	88.9	6.0

***p<0.00001**

Table 3- Mandibular Components

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
SNB (°)*	120	76.9	3.7	40	76.0	3.1	40	76.9	3.7	40	77.8	4.0
B-Nperp (mm)*	120	-10.2	4.7	40	-11.6	4.1	40	-10.0	4.7	40	-9.1	5.1
Pog-Nperp (mm)*	120	-9.3	5.5	40	-11.1	4.9	40	-8.9	5.3	40	-7.9	5.8
Mand Unit Length (Co-Gn) (mm)*	120	111.7	8.0	40	106.7	6.7	40	112.7	6.4	40	115.8	8.1

***p<0.00001**

Table 4-Maxillomandibular Relationships

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
ANB (°)*	120	4.2	2.4	40	5.5	1.9	40	3.6	2.3	40	3.6	2.4
Wits (mm)*	120	0.2	3.3	40	2.1	3.1	40	-1.0	3.0	40	-0.5	3.2
Mx/Md Diff (Co-Gn-Co-ANS) (mm)*	120	24.7	5.8	40	21.1	4.4	40	26.2	5.4	40	27.0	5.8

***p<0.00001**

Table 5-Vertical and Horizontal Components

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
FH-SN (°)	120	6.7	2.4	40	6.4	2.7	40	7.0	2.6	40	6.7	2.5
FMA (MP-FH) (°)	120	26.9	4.8	40	27.5	4.7	40	26.9	4.7	40	26.2	4.9
LFH/TFH (ANS-Me:N-Me) (%)*	120	54.6	2.7	40	54.0	2.7	40	54.6	2.7	40	55.2	2.5
MP-SN (°)	120	33.6	5.2	40	34.0	4.9	40	34.0	5.0	40	33.0	5.7

***p<0.00001**

Table 6-Maxillary Dentoalveolar Component

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
U1-SN (°)	120	103.9	7.7	40	103.9	8.2	40	103.5	7.8	40	104.2	7.3
U1-Palatal Plane (°)	120	110.8	7.6	40	110.6	8.1	40	110.8	8.0	40	111.0	6.8
U1-PP(UADH)(mm)*	119	27.3	3.1	40	26.6	3.0	39	27.2	3.2	40	28.2	3.1
U6-PP(UPDH)(mm)*	120	20.7	2.7	40	19.3	2.2	40	20.7	2.4	40	22.1	2.7
U1-NA (mm)	120	3.6	2.5	40	3.9	2.7	40	3.4	2.5	40	3.7	2.3

***p<0.00001**

Table 7-Mandibular Dentoalveolar Component

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
L1-NB (mm)*	120	5.1	2.4	40	4.0	2.2	40	5.8	2.2	40	5.4	2.4
IMPA (L1-MP) (°)**	120	95.5	7.3	40	93.0	7.6	40	97.5	6.9	40	95.9	7.0
L1-MP (LADH) (mm)*	120	38.0	3.3	40	37.3	3.3	40	37.6	3.1	40	39.0	3.4
L6-MP (LPDH) (mm)*	120	28.2	3.0	40	26.2	2.6	40	28.9	2.8	40	29.5	2.8

***p<0.00001, **p<0.00003**

Table 8-Dentoalveolar Relationship

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Overjet (mm)*	120	4.3	2.4	40	7.1	2.1	40	2.6	0.6	40	3.4	0.7
Overbite (mm)*	120	2.8	1.9	40	4.5	2.0	40	1.5	1.0	40	2.4	1.0
Interincisal Angle (°)	120	126.8	10.2	40	129.2	10.6	40	124.4	10.5	40	126.7	9.1

***p<0.00001**

Table 9-Soft Tissue Component

Variable	All			T1			T2			T3		
	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD
Facial Convexity (G'-Sn-Po') (°)*	120	16.5	5.1	40	18.1	4.3	40	15.8	5.3	40	15.5	5.3
Upper Lip-S Line (mm)**	119	0.3	2.4	40	1.7	2.1	40	-0.1	2.0	39	-0.8	2.4
Lower Lip-S Line (mm)**	119	0.9	2.2	40	1.5	2.1	40	1.0	2.0	39	0.1	2.3

***p<0.00004, **p<0.00001**

This repeated measures ANOVA only enabled us to determine whether the means were significantly different. However, it did not establish which time period the statistically significant different means were seen. In order to determine this, a Bonferroni correction post hoc test was carried out and revealed the results below with the level of significance at p≤0.02.

Table 10-Bonferroni Correction Analysis

Bonferroni Correction			
	T1 to T2	T2 to T3	T1 to T3
Mx Unit Length (Co-ANS) (mm)	0.51	0.05	0.01
SNB (°)	0.26	0.24	0.02
B-Nperp (mm)	0.13	0.40	0.02
Pog-Nperp (mm)	0.08	0.40	0.01
Mand Unit Length (Co-Gn) (mm)	0.001	0.09	<0.00001
ANB (°)	0.0004	0.90	0.0003
Wits (mm)	0.00002	0.44	0.001
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	0.00004	0.57	<0.00001
LFH/TFH (ANS-Me:N-Me) (%)	0.31	0.33	0.04
U1-PP (UADH) (mm)	0.39	0.14	0.02
U6-PP (UPDH) (mm)	0.02	0.02	<0.00001
L1-NB (mm)	0.001	0.39	0.01
IMPA (L1-MP) (°)	0.01	0.34	0.08
L1-MP (LADH) (mm)	0.66	0.06	0.02
L6-MP (LPDH) (mm)	0.0001	0.36	<0.00001
Overjet (mm)	<0.00001	0.13	<0.00001
Overbite (mm)	<0.00001	0.04	<0.00001
Facial Convexity (G'-Sn-Po') (°)	0.04	0.78	0.02
Upper Lip-S Line (mm)	0.01	0.22	<0.00001
Lower Lip-S Line (mm)	0.28	0.08	0.004

Table 11-Paired Sample t-Test

Variables	Difference T1-T2		Difference T2-T3		Difference T1-T3	
	Mean	SD	Mean	SD	Mean	SD
Mx Unit Length (Co-ANS) (mm)	-0.8	3.4	***-2.4****	2.8	***-3.2****	4.1
SNB (°)	***-0.9****	1.4	***-1.0****	1.3	***-1.9****	2.0
B-Nperp (mm)	-1.6	3.0	-0.9	3.2	***-2.5****	3.0
Pog-Nperp (mm)	***-2.1****	3.3	-1.0	3.6	***-3.2****	3.5
Mand Unit Length (Co-Gn) (mm)	***-6.0****	3.8	***-3.0****	3.6	***-9.1****	5.3
ANB (°)	***1.8****	1.2	0.1	0.9	***1.9****	1.4
Wits (mm)	***3.1****	3.4	-0.6	3.5	***2.5****	4.1
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	***-5.2****	2.8	-0.7	3.0	***-5.9****	3.6
LFH/TFH (ANS-Me:N-Me) (%)	-0.6	1.6	***-0.6****	0.9	***-1.2****	1.6
U1-PP(UADH)(mm)	-0.6	2.0	***-1.0****	1.3	***-1.7****	1.9
U6-PP (UPDH) (mm)	***-1.4****	1.4	***-1.4****	1.6	***-2.8****	2.1
L1-NB (mm)	***-1.8****	1.4	0.5	0.9	***-1.3****	1.5
IMPA (L1-MP) (°)	***-4.5****	6.7	1.6	4.0	-2.9	6.5
L1-MP (LADH) (mm)	-0.3	1.6	***-1.4****	1.4	***-1.7****	2.1
L6-MP (LPDH) (mm)	***-2.6****	1.8	-0.6	1.4	***-3.3****	1.8
Overjet (mm)	***4.5****	2.2	***-0.8****	0.7	***3.7****	1.9
Overbite (mm)	***3.0****	2.0	***-0.9****	1.0	***2.1****	1.8
Facial Convexity (G'-Sn-Po') (°)	2.3	4.4	0.3	3.7	***2.6****	3.1
Upper Lip-S Line (mm)	***1.8****	1.6	***0.7****	1.1	***2.5****	1.6
Lower Lip-S Line (mm)	0.5	1.5	***0.9****	1.0	***1.4****	1.5

***p≤0.05. NOTE: Negative values indicate increase in measurement from one time period to the next and positive values indicate a decrease.**

Treatment Changes T1-T2 (Pre-Treatment to Post-Treatment)

Many of the craniofacial variables, especially the ones important relative to Class II correction, showed statistically significant changes. More specifically, a statistically significant decrease was observed for the Wits and ANB. The lower incisors became more proclined and protrusive. The upper lip became more retrusive to the S Line as compared to pre-treatment. Both overjet and overbite showed a statistically significant decrease.

Treatment Changes T2-T3 (Post-Treatment to Post-Retention)

The data revealed that SNB increased by a mean of 1.0±1.3mm. Overjet and overbite increased by a mean of 0.8±0.7mm and 0.9±1.0mm respectively. A significant increase was seen in the maxillary unit length and several maxillary and mandibular dentoalveolar measurements (U1-PP, U6-PP, L1-MP).

Treatment Changes T1-T3 (Pre-Treatment to Post-Retention)

Nearly all of the cephalometric variables except IMPA (L1-MP) showed statistically significant changes. More specifically, a statistically significant decrease was observed for the Wits and ANB. The lower incisors became more proclined and protrusive. The SNB significantly increased and the overjet and overbite significantly decreased. The facial convexity significantly decreased and the upper and lower lip became less protrusive as evidenced by the decrease in means for facial convexity and the upper lip-S Line and lower lip-S line.

<u>Dahlberg Error Study</u>

Table 12-Dahlberg for Pre-Treatment (T1)

T1 (Pre-Treatment)						
	First Measurement		Second Measurement		paired t-test (p-value)	Error
	mean	SD	mean	SD		
Maxillary Component						
SNA (°)	81.7	3.8	81.4	3.9	>0.05	0.7
A-Nperp (mm)	-2.0	3.1	-2.2	3.0	>0.05	1.0
Mx Unit Length (Co-ANS) (mm)	85.6	6.2	86.5	6.2	>0.05	1.4
Mandibular Component						
SNB (°)	76.4	3.4	76.0	3.5	>0.05	0.6
B-Nperp (mm)	-11.6	4.6	-11.8	4.4	>0.05	1.5
Pog-Nperp (mm)	-10.9	5.3	-11.2	5.0	>0.05	1.8
Mand Unit Length (Co-Gn) (mm)	107.2	5.9	107.1	5.0	>0.05	1.5
Maxillomandibular Relationship						
ANB (°)	5.4	1.9	5.3	1.9	>0.05	0.5
Wits (mm)	2.3	3.2	1.1	3.2	>0.05	1.7
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	21.5	4.5	20.6	4.0	>0.05	1.6
Vertical Component						
FH-SN (°)	6.0	2.1	6.3	2.0	>0.05	1.1
FMA (MP-FH) (°)	27.2	5.2	27.3	5.0	>0.05	1.3
LFH/TFH (ANS-Me:N-Me) (%)	54.4	2.6	54.5	2.9	>0.05	0.8
MP-SN (°)	33.3	5.3	33.7	5.6	>0.05	8.8
Maxillary Dentoalveolar Component						
U1-SN (°)	104.7	9.7	102.9	9.0	≤0.05*	2.2
U1-Palatal Plane (°)	110.3	9.4	108.4	8.5	>0.05	2.5
U1-NA (mm)	4.2	3.1	4.3	3.0	>0.05	0.9
Mandibular Dentoalveolar Component						
L1-NB (mm)	4.0	2.5	4.0	2.5	>0.05	0.3
IMPA (L1-MP) (°)	92.9	8.8	94.4	9.1	>0.05	1.7
L1-MP (LADH) (mm)	37.5	3.6	37.6	3.4	>0.05	0.5
L6-MP (LPDH) (mm)	26.2	3.0	26.2	2.8	>0.05	0.7
Dentoalveolar Relationship						
Overjet (mm)	7.2	2.3	7.3	2.4	>0.05	0.4
Overbite (mm)	4.9	2.0	5.2	2.0	>0.05	0.6
Interincisal Angle (°)	129.1	11.8	130.0	11.0	>0.05	2.4
Soft Tissue Relationship						
Facial Convexity (G'-Sn-Po') (°)	17.5	4.2	16.8	4.2	≤0.05*	0.8

***Statistically significant at p≤0.05**

The above results in Table 11 showed a systematic error for 2 of the variables (U1-SN, Facial Convexity). The range of casual errors for the pre-treatment period (T1) varied from 0.3 to 2.5 with most of the variables below 2° or 2mm.

Table 13—Dahlberg for Post-Treatment (T2)

T2 (Post-Treatment)						
	First Measurement		Second Measurement		Paired t-test (p-value)	Error
	mean	SD	mean	SD		
Maxillary Component						
SNA (°)	80.9	4.5	80.9	4.4	>0.05	0.7
A-Nperp (mm)	-2.1	3.6	-1.8	3.8	>0.05	1.1
Mx Unit Length (Co-ANS) (mm)	86.5	5.3	88.8	5.2	≤0.05*	2.4
Mandibular Component						
SNB (°)	77.3	3.9	77.2	4.0	>0.05	0.4
B-Nperp (mm)	-9.4	4.9	-9.2	4.9	>0.05	1.6
Pog-Nperp (mm)	-8.3	5.4	-8.1	5.2	>0.05	1.8
Mand Unit Length (Co-Gn) (mm)	113.3	6.0	114.0	5.4	>0.05	2.2
Maxillomandibular Relationship						
ANB (°)	3.7	2.7	3.8	2.5	>0.05	0.5
Wits (mm)	-1.4	3.1	-0.5	2.1	>0.05	1.7
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	26.7	5.2	25.1	4.9	≤0.05*	1.6
Vertical Component						
FH-SN (°)	7.1	2.6	7.3	2.5	>0.05	1.0
FMA (MP-FH) (°)	26.3	5.0	26.0	5.2	>0.05	1.1
LFH/TFH (ANS-Me:N-Me) (%)	54.9	2.9	55.3	2.8	>0.05	0.6
MP-SN (°)	33.4	5.7	33.3	5.7	>0.05	0.6
Maxillary Dentoalveolar Component						
U1-SN (°)	104.1	8.7	102.8	7.4	>0.05	1.7
U1-Palatal Plane (°)	110.4	8.2	109.1	7.1	>0.05	1.9
U1-NA (mm)	3.2	2.9	3.1	2.7	>0.05	0.7
Mandibular Dentoalveolar Component						
L1-NB (mm)	5.7	2.1	5.8	2.1	>0.05	0.3
IMPA (L1-MP) (°)	96.7	6.2	98.7	5.6	≤0.05*	2.6
L1-MP (LADH) (mm)	37.9	3.5	38.0	3.3	>0.05	0.7
L6-MP (LPDH) (mm)	29.1	3.1	29.1	2.8	>0.05	0.7
Dentoalveolar Relationship						
Overjet (mm)	2.6	0.5	2.7	0.5	>0.05	0.2
Overbite (mm)	1.6	0.8	1.7	0.8	>0.05	0.5
Interincisal Angle (°)	124.9	10.6	125.2	8.2	>0.05	4.1
Soft Tissue Relationship						
Facial Convexity (G'-Sn-Po') (°)	15.2	5.0	14.4	5.1	≤0.05*	0.9

***Statistically significant at p≤0.05**

The above results in Table 12 showed systematic errors for 4 of the variables (Mx Unit Length, Mx/Md Diff (Co-Gn - Co-ANS), L1-MP, Facial Convexity (G'-Sn-Po')). The range of casual errors varied from 0.3 to 2.2, with most of the variables below 2° or 2mm.

Table 14-Dahlberg for Post-Retention (T3)

T3 (Post-Retention)						
	First Measurement		Second Measurement		Paired t-test (p-value)	Error
	mean	SD	mean	SD		
Maxillary Component						
SNA (°)	81.6	4.2	81.9	4.2	>0.05	0.6
A-Nperp (mm)	-1.7	3.5	-1.9	3.4	>0.05	1.4
Mx Unit Length (Co-ANS) (mm)	88.9	6.2	90.1	5.4	>0.05	2.4
Mandibular Component						
SNB (°)	78.2	4.2	78.2	4.2	>0.05	0.4
B-Nperp (mm)	-9.1	5.3	-8.9	5.6	>0.05	1.6
Pog-Nperp (mm)	-7.8	5.9	-7.8	6.3	>0.05	1.7
Mand Unit Length (Co-Gn) (mm)	115.9	6.8	115.9	6.0	>0.05	2.4
Maxillomandibular Relationship						
ANB (°)	3.7	2.7	3.8	2.3	>0.05	0.5
Wits (mm)	0.2	3.3	-1.7	2.9	≤0.05	2.1
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	27.0	5.6	25.8	5.3	>0.05	1.6
Vertical Component						
FH-SN (°)	6.4	2.4	6.5	2.2	>0.05	1.0
FMA (MP-FH) (°)	25.9	5.3	25.4	5.6	>0.05	1.1
LFH/TFH (ANS-Me:N-Me) (%)	55.5	2.4	55.6	2.9	>0.05	0.8
MP-SN (°)	32.2	6.2	31.9	6.1	>0.05	0.8
Maxillary Dentoalveolar Component						
U1-SN (°)	104.6	8.4	104.0	7.8	>0.05	1.3
U1-Palatal Plane (°)	110.3	7.0	109.3	7.1	>0.05	1.6
U1-NA (mm)	3.5	2.7	0.4	2.6	>0.05	0.7
Mandibular Dentoalveolar Component						
L1-NB (mm)	5.2	2.4	5.4	2.3	>0.05	0.3
IMPA (L1-MP) (°)	95.7	6.6	97.2	6.2	≤0.05	1.8
L1-MP (LADH) (mm)	39.1	3.7	38.9	3.3	>0.05	0.7
L6-MP (LPDH) (mm)	29.4	2.8	30.0	2.7	>0.05	1.2
Dentoalveolar Relationship						
Overjet (mm)	3.5	0.8	3.5	0.8	>0.05	0.3
Overbite (mm)	2.5	1.0	2.8	1.1	>0.05	0.4
Interincisal Angle (°)	127.5	8.9	126.9	8.4	>0.05	1.6
Soft Tissue Relationship						
Facial Convexity (G'-Sn-Po') (°)	14.7	5.4	13.9	5.8	≤0.05	0.9

***Statistically significant at p≤0.05**

The above results in Table 13 showed systematic errors for 3 of the variables (Wits, L1-MP, Facial Convexity). The range of casual errors varied from 0.3 to 2.2, with most of the variables below 2° or 2mm.

Figure 4 (Skeletal AP values T1-T2)

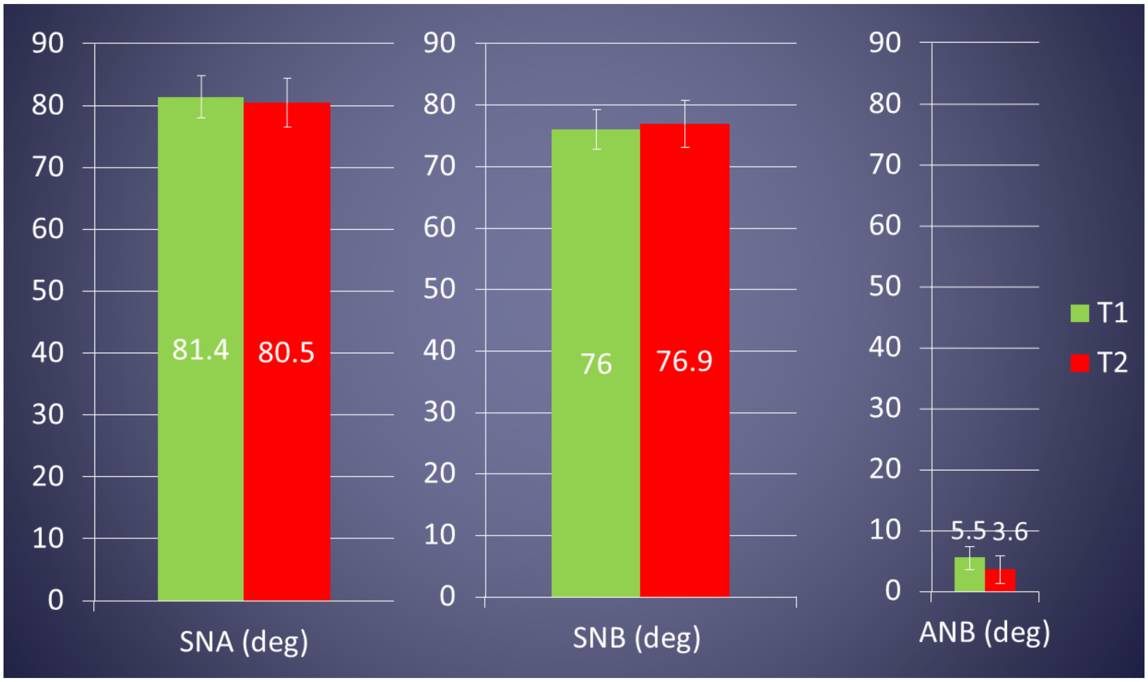


Table 15 (Comparison of Skeletal AP T1-T2 difference with literature)

Variable	Investigator	Franchi et al (2011) Forsus	Lerstol et al (2010) Activator-Headgear Combo	Malta et al (2010) Bionator	Heinig (2001) Forsus spring	Janson et al (2004) Activator-Headgear	Miller et al (2013) Forsus
Max component							
SNA (deg)	0.9±1.5 degree **decrease**	1.6±1.4 degree **decrease**				1.36±1.67 degree **decrease**	
Man Component							
SNB (deg)	0.9±1.4 degree **increase**	0.3±1.4 degree **increase**			0.54 degree **increase**	1.2±1.7 degree **increase**	
Maxillomandibular Relationship							
ANB (deg)	1.8±1.2 degree **decrease**	1.9±1.2 degree **decrease**	2.3±1.7 degree **decrease**				2.4±3.5 degree **decrease**

Figure 5 (Skeletal AP T2-T3)

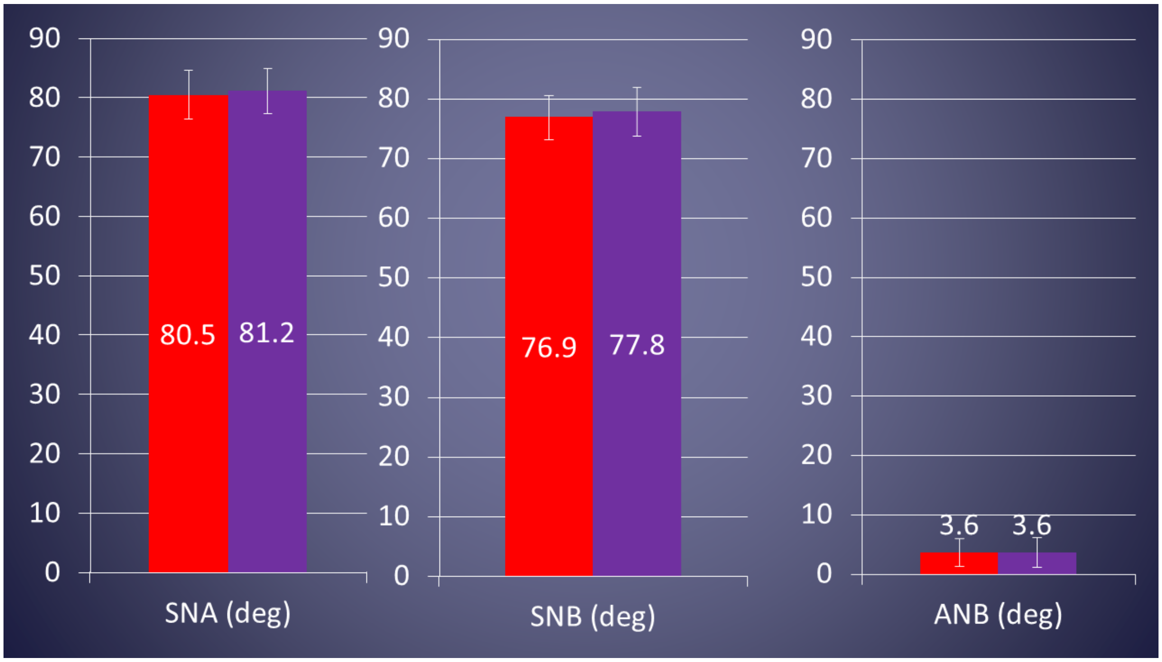


Figure 6 (Skeletal AP T2-T3 Difference)

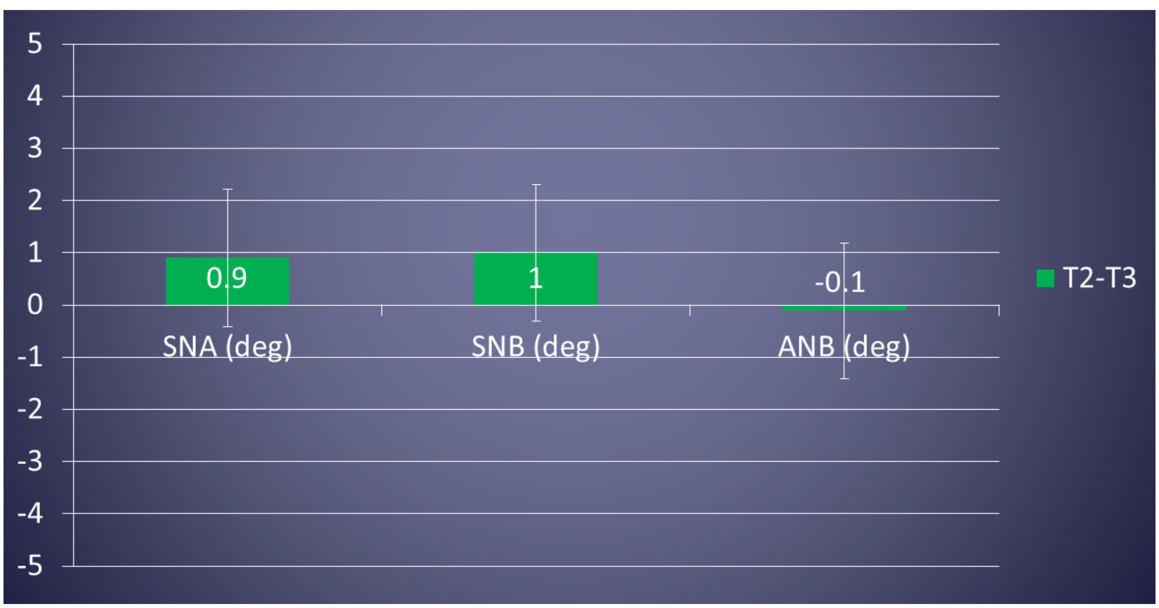


Table 16 (Comparison of skeletal AP T2-T3 difference with literature)

Variable	Investigator	Franchi et al (2013) Bionator or Activator	Lerstol et al (2010) Activator-Headgear	Bock et al (2003) Herbst	Janson et al (2004) Activator-Headgear
Max component					
SNA	0.9±1.9 degree **increase**		0.5±1.4 degree **increase**		0.56 ±2.03 degree **increase**
U1-SN	0.7±3.7 degree **increase**		0.8±5.9 degree **increase**		
U1-PP	0.1±3.5 degree **increase**				0.53±4.31 degree **increase**
Man Component					
SNB	1.0±1.3 degree **increase**		1.0±1.8 degree **increase**		
IMPA	1.6±4.0 degree **decrease**	1.2±5.9 degree **increase**	1.3±4.0 degree **decrease**		
FMA	0.6±1.9 degree **decrease**	2.70±2.5 degree **decrease**			0.95±1.93 degree **decrease**
SN-MP	1±1.8 degree **decrease**			1.6±1.9 degree **decrease**	0.92±2.09 degree **decrease**
Maxillomandibular Relationship (Skeletal and Dentoalveolar)					
ANB	0.1±0.9 degree **decrease**		0.5±1.4 degree **decrease**	0.20±0.82 degree **decrease**	0.22±1.28 degree **increase**

Figure 7 (Wits T1-T2)(mm)

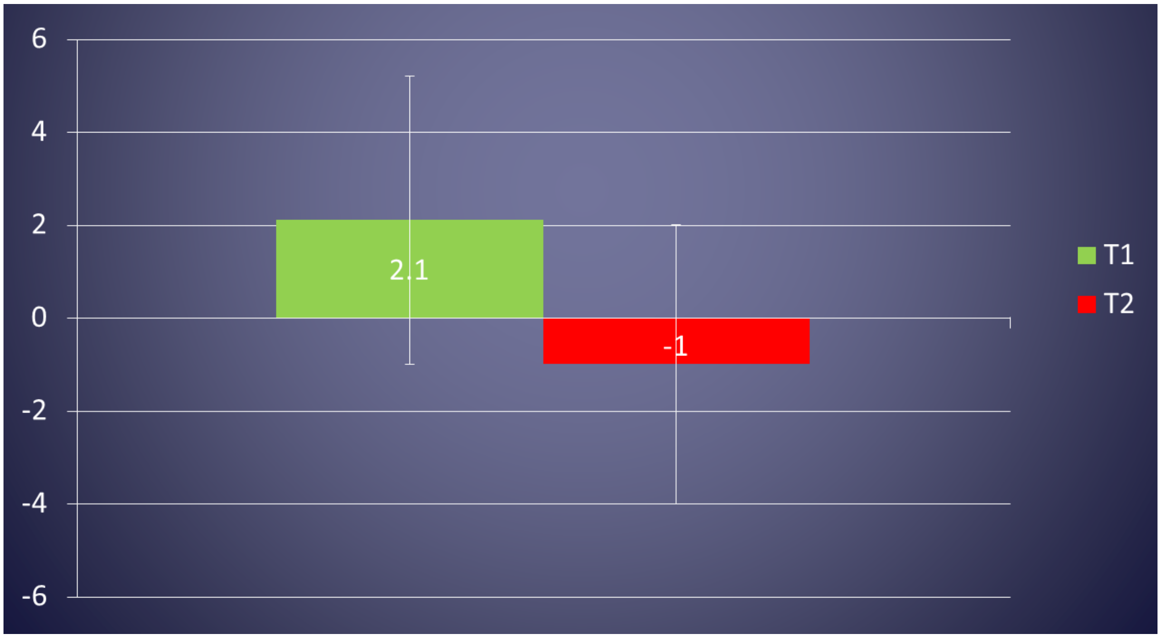


Table 17 (Comparison of Wits T1-T2 difference with literature)

Variable	Investigator	Franchi et al (2011) Forsus	Lerstol et al (2010) Activator-Headgear Combo	Malta et al (2010) Bionator	Heinig (2001) Forsus spring	Janson et al (2004) Activator-Headgear	Miller et al (2013) Forsus
Wits (mm)	3.1±3.4 mm **decrease**	2±3 mm **decrease**		1.9±1.6 mm **decrease**			

Figure 8 (Wits T2-T3 difference)(mm)

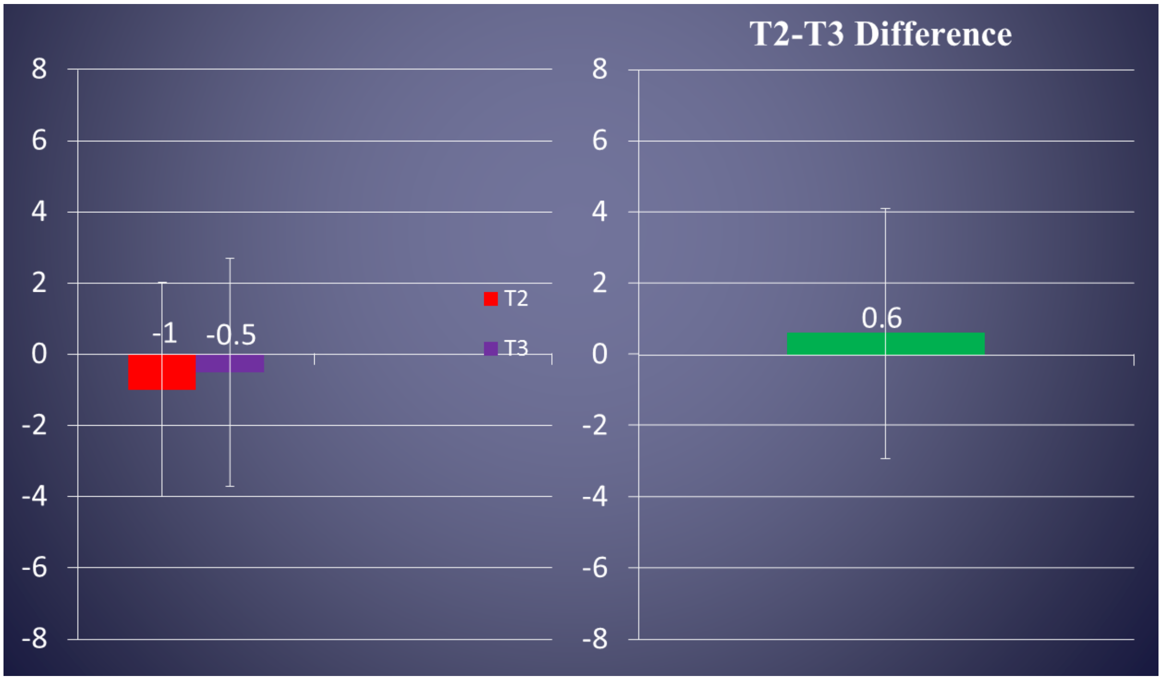


Table 18 (Comparison of Wits T2-T3 difference with literature)

Variable	Investigator	Franchi et al (2013) Bionator or Activator	Lerstol et al (2010) Activator-Headgear	Malta et al (2010) Bionator	Janson et al (2004) Activator-Headgear
Maxillomandibular Relationship (Skeletal and Dentoalveolar)					
ANB	0.1±0.9 degree **decrease**		0.5±1.4 degree **decrease**		0.22±1.28 degree **increase**
Wits	0.6±3.5 mm **increase**			0.5mm mean **increase**	

Figure 9 (Skeletal Vertical T1-T2)

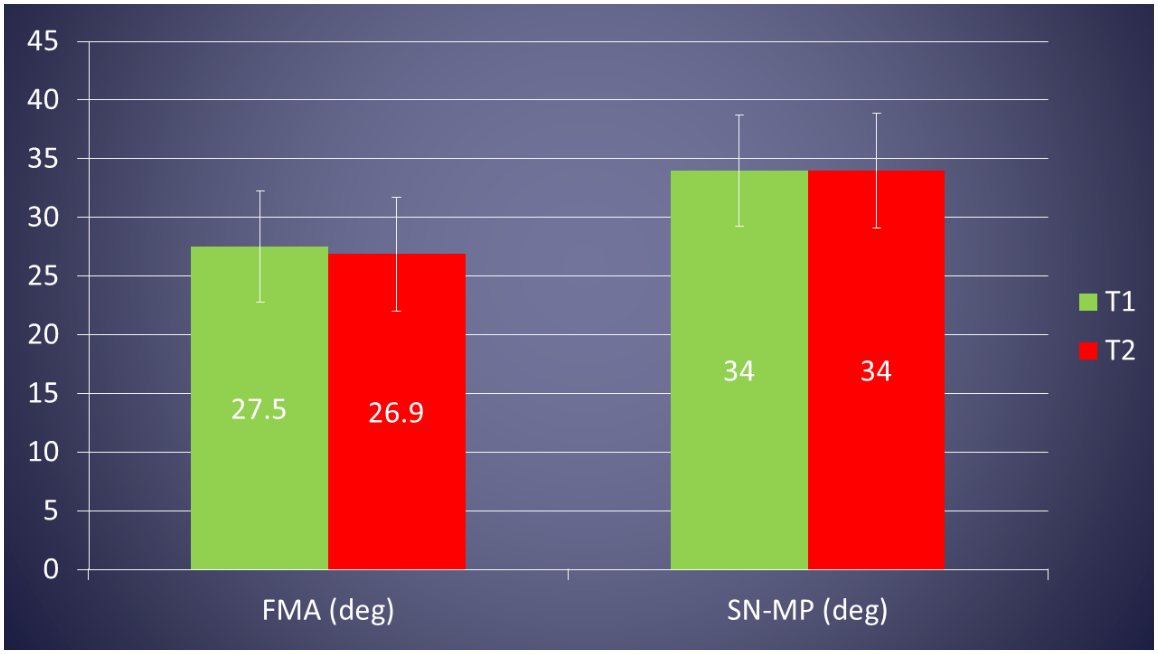


Table 19 (Comparison of Skeletal Vertical T1-T2 difference with literature)

Variable	Investigator	Franchi et al (2011) Forsus	Lerstol et al (2010) Activator-Headgear Combo	Malta et al (2010) Bionator	Heinig (2001) Forsus spring	Janson et al (2004) Activator-Headgear	Miller et al (2013) Forsus
FMA (deg)	0.5±2.4 degree **decrease**	1.1±2.2 degree **decrease**				0.95±1.93 degree **decrease**	

Figure 10 (Skeletal Vertical T2-T3)

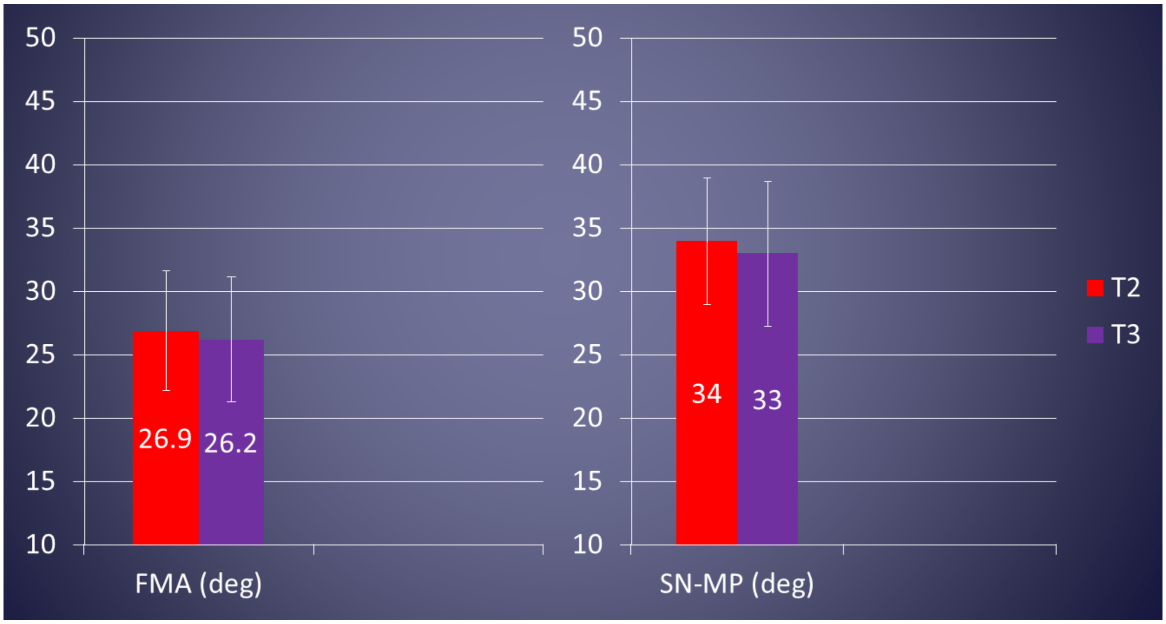


Figure 11 (Skeletal Vertical T2-T3 Difference)

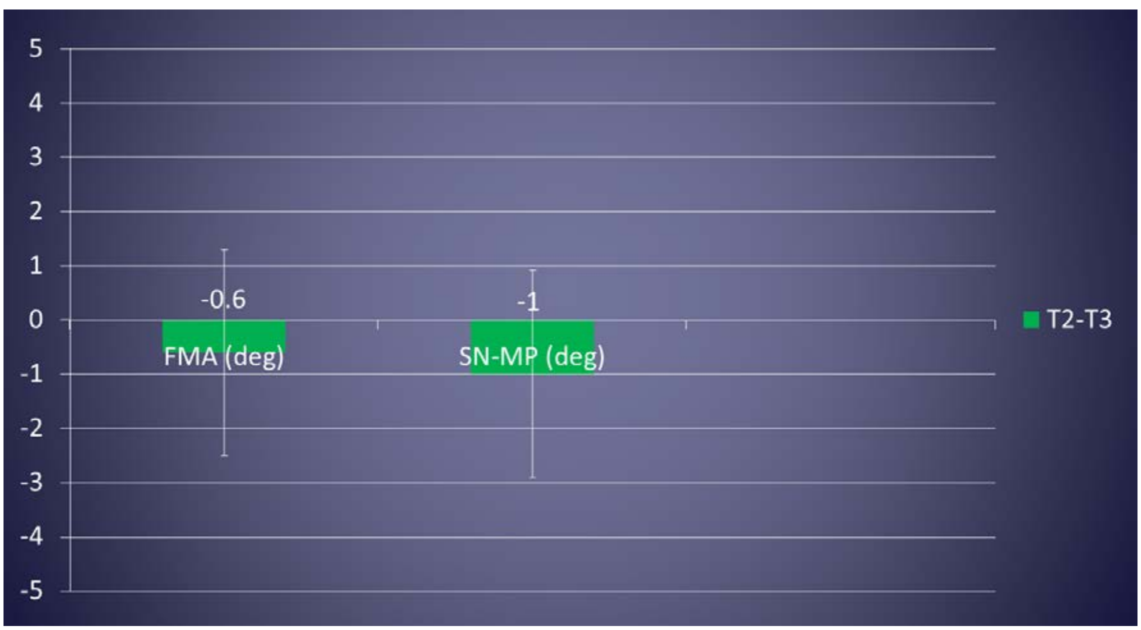


Table 20 (Comparison of Skeletal Vertical T2-T3 difference with literature)

Variable	Investigator	Franchi et al (2013) Bionator or Activator	Lerstol et al (2010) Activator-Headgear	Bock et al (2003) Herbst	Janson et al (2004) Activator-Headgear
Max component					
SNA	0.9±1.9 degree **increase**		0.5±1.4 degree **increase**		0.56 ±2.03 degree **increase**
U1-SN	0.7±3.7 degree **increase**		0.8±5.9 degree **increase**		
U1-PP	0.1±3.5 degree **increase**				0.53±4.31 degree **increase**
Man Component					
SNB	1.0±1.3 degree **increase**		1.0±1.8 degree **increase**		
IMPA	1.6±4.0 degree **decrease**	1.2±5.9 degree **increase**	1.3±4.0 degree **decrease**		
FMA	0.6±1.9 degree **decrease**	2.70±2.5 degree **decrease**			0.95±1.93 degree **decrease**
SN-MP	1±1.8 degree **decrease**			1.6±1.9 degree **decrease**	0.92±2.09 degree **decrease**

Figure 12 (Dental AP T1-T2)

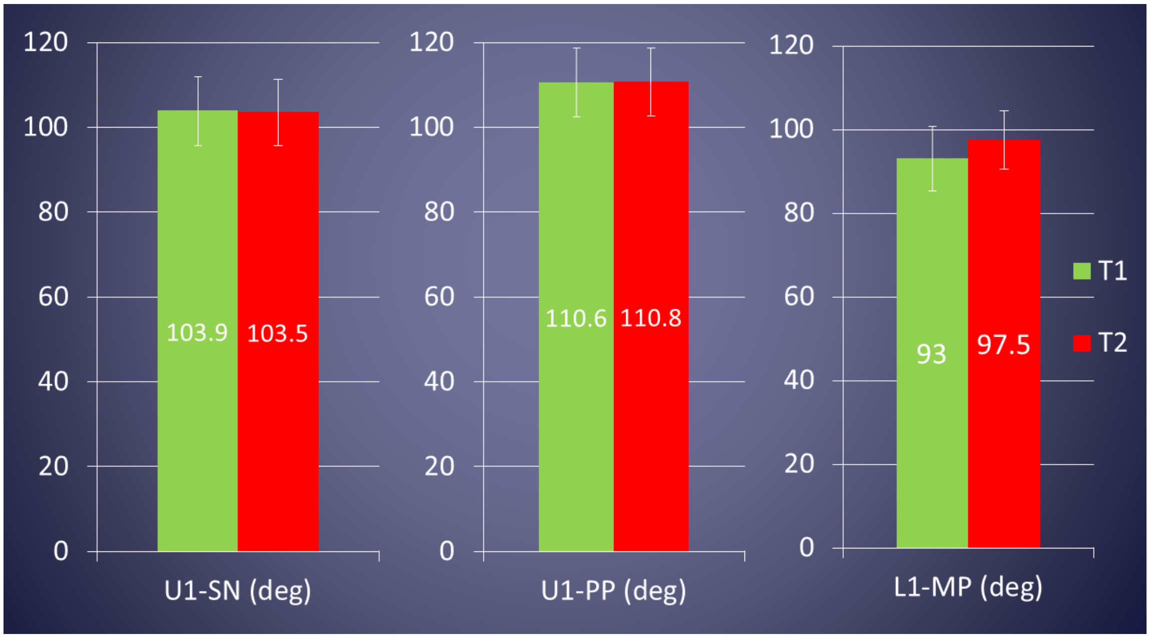


Table 21 (Comparison of Dental AP T1-T2 difference with literature)

Variable	Investigator	Franchi et al (2011) Forsus	Lerstol et al (2010) Activator-Headgear Combo	Jones et al (2008) Forsus	Heinig (2001) Forsus spring	Janson et al (2004) Activator-Headgear	Miller et al (2013) Forsus
Man Component							
SNB (deg)	0.9±1.4 degree **increase**	0.3±1.4 degree **increase**			0.54 degree **increase**	1.2±1.7 degree **increase**	
IMPA (deg)	4.5±6.7 degree **increase**	6.1±6.3 degree **increase**		6.3±7.0 degree **increase**	9.6 degree mean **increase**		3.4±7.7 degree **increase**

Figure 13 (Dental AP T2-T3)

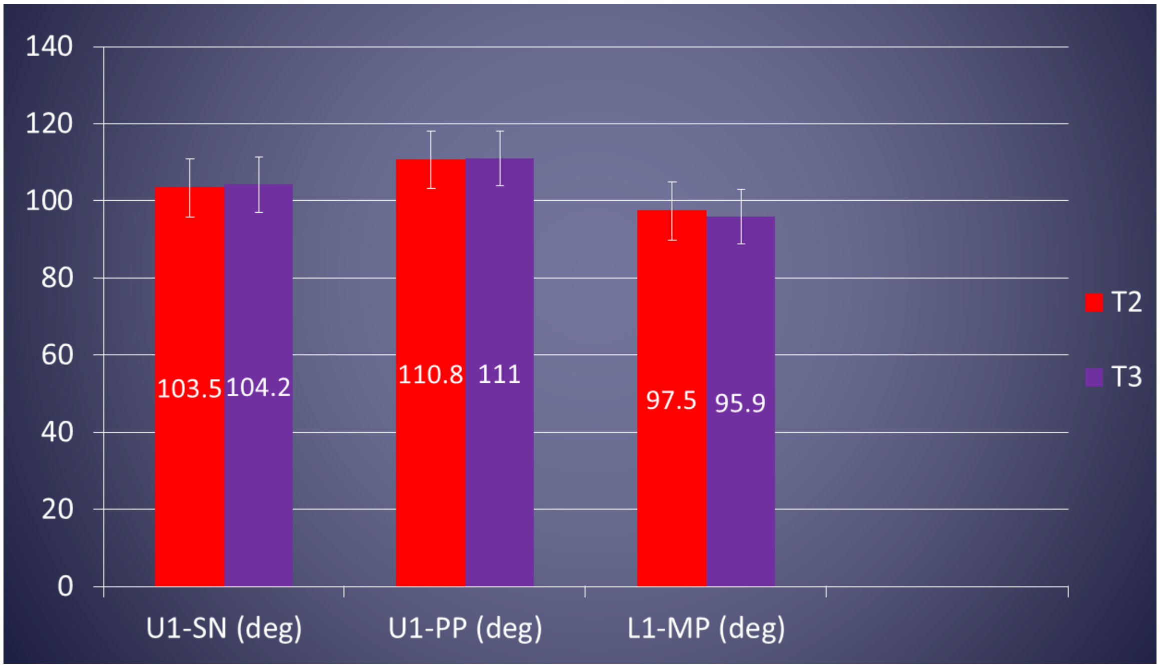


Figure 14 (Dental AP T2-T3 difference)

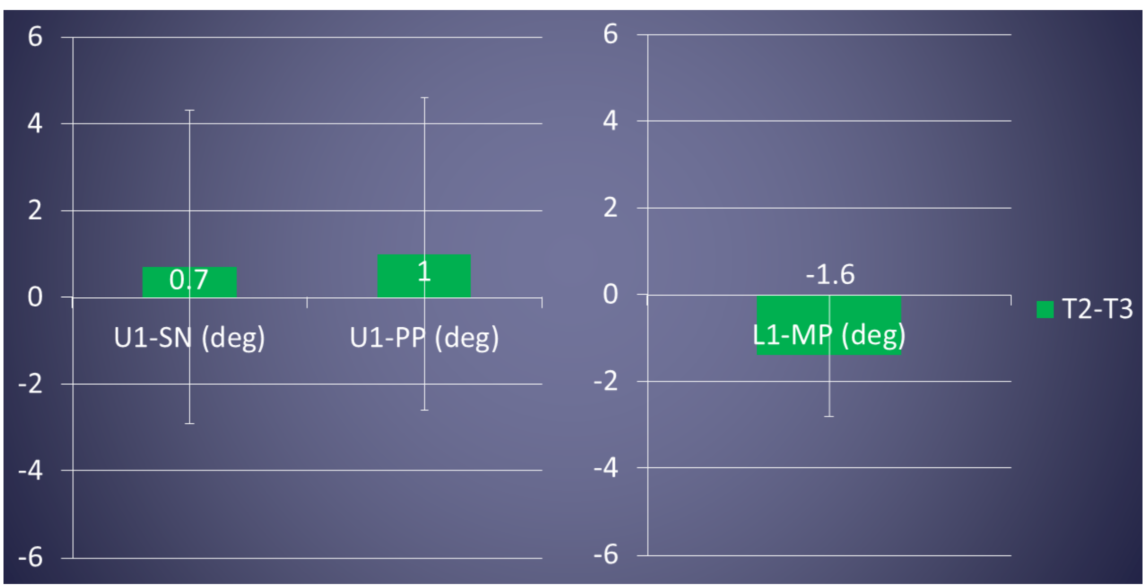


Table 22 (Comparison of Dental AP T2-T3 difference with literature)

Variable	Investigator	Franchi et al (2013) Bionator or Activator	Lerstol et al (2010) Activator-Headgear	Bock et al (2003) Herbst	Janson et al (2004) Activator-Headgear
Max component					
U1-SN	0.7±3.7 degree **increase**		0.8±5.9 degree **increase**		
U1-PP	0.1±3.5 degree **increase**				0.53±4.31 degree **increase**
Man Component					
IMPA	1.6±4.0 degree **decrease**	1.2±5.9 degree **increase**	1.3±4.0 degree **decrease**		

Figure 15 (Overjet and Overbite T1-T2)(mm)

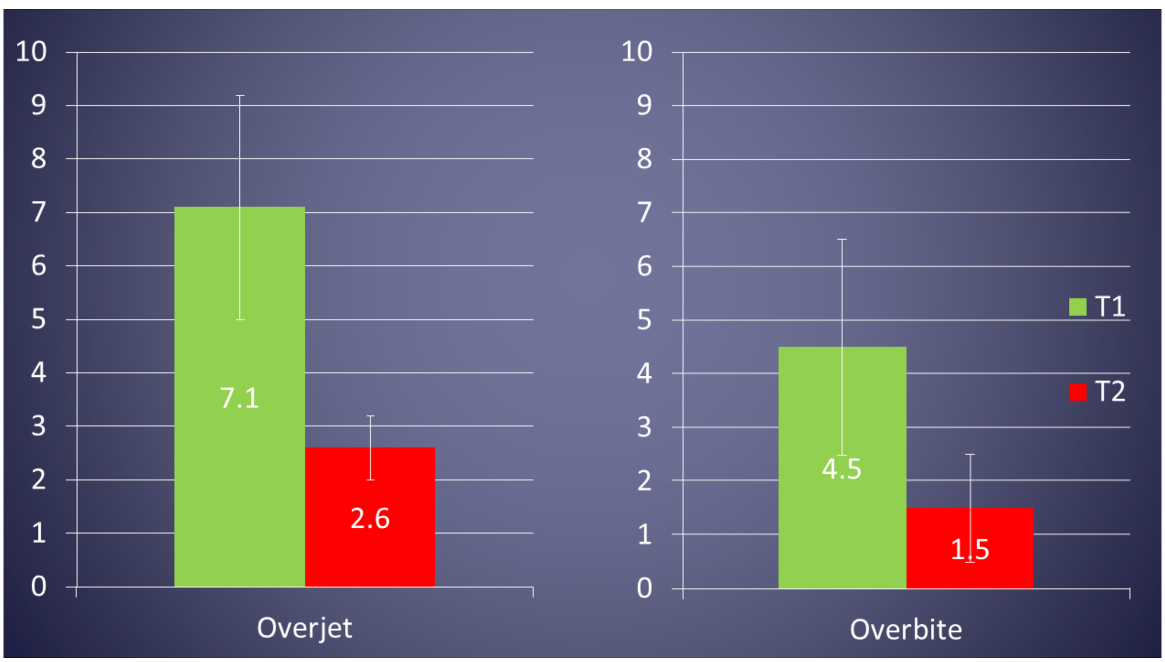


Figure 16 (Overjet and Overbite T2-T3)(mm)

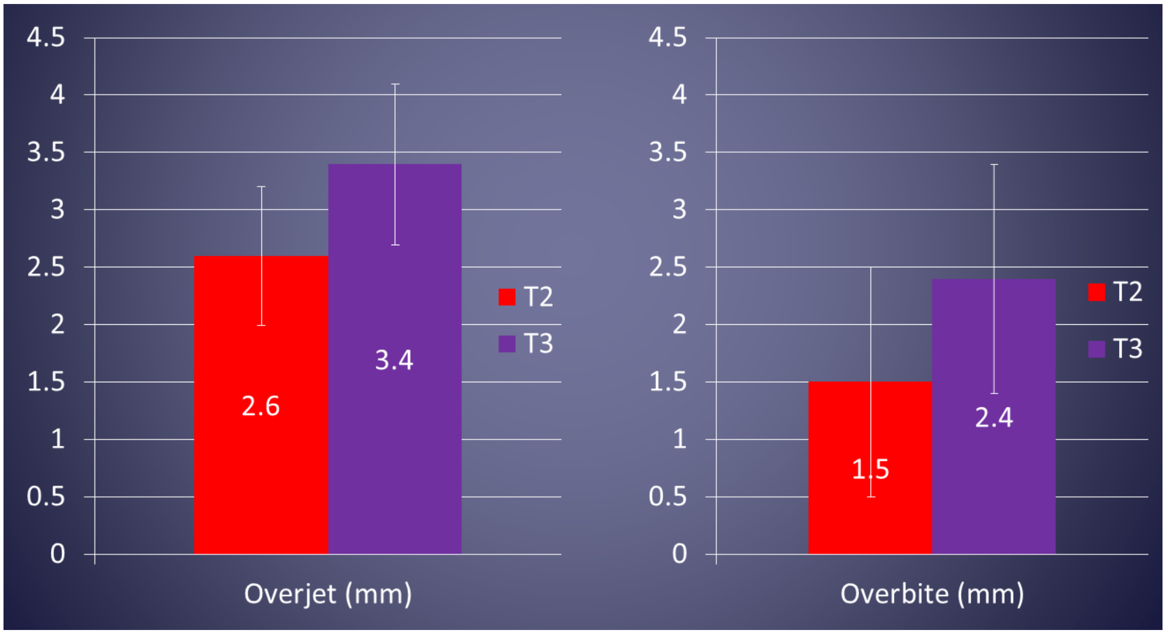


Figure 17 (Overjet and Overbite T2-T3 difference)

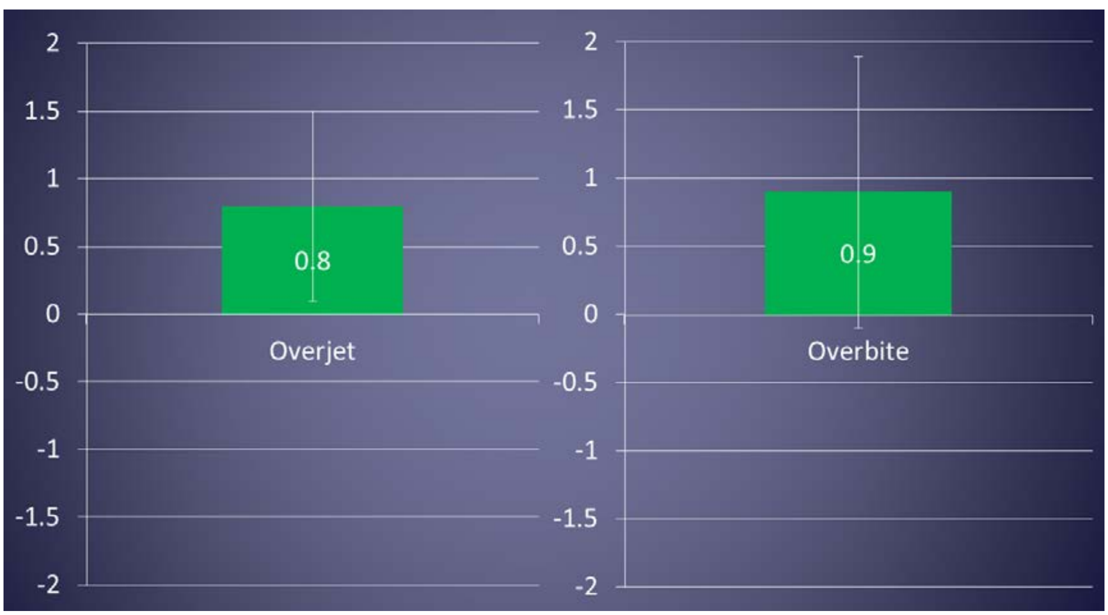


Table 23 (Comparison of Overjet and Overbite T2-T3 difference with literature)

Variable	Investigator	Franchi et al (2013) Bionator or Activator	Lerstol et al (2010) Activator-Headgear	Malta et al (2010) Bionator	Janson et al (2004) Activator-Headgear
Maxillomandibular Relationship (Skeletal and Dentoalveolar)					
ANB	0.1±0.9 degree **decrease**		0.5±1.4 degree **decrease**		0.22±1.28 degree **increase**
Wits	0.6±3.5 mm **increase**			0.5mm mean increase	
Overjet	0.8±0.70 mm **increase**		0.1±1.7 mm **increase**		0.4±1.31 mm **increase**
Overbite	0.9±1.0 mm **increase**		0.3±0.7 mm **increase**		1.05±1.11 mm **increase**

DISCUSSION:

Previous studies (Jones et al 2008, Franchi et al 2011) have reported on the Forsus^{TM} as an effective appliance in managing patients with Class II malocclusion.[4,30] Although this appliance has been around for more than a decade, no previous research has focused on the stability or even post-retention changes of the Class II correction in response to this treatment modality. Since this study lacked a control group with which to compare the post-retention changes observed in this sample population and the fact that observed changes were cephalometric in nature, the term “stability” probably should not be utilized. With this in mind, the author, instead, investigated the dentoskeletal post-retention changes about 2.2 years after treatment with fixed appliances and the Forsus^{TM}. A much longer post-treatment observation period, perhaps 6 years or more, could have obviated the need for a control group as there are studies by other authors (Francisconi et al 2013, Lerstol et al 2010) who have claimed “stable” results after mean 10 year and 13 year follow-ups respectively without comparison to untreated groups.[25,40] Nevertheless, relevant information can still be garnered in the post-treatment period for this particular study.

Dahlberg Error

Here is a table summarizing the error measurements for each time period.

Variable	T1	T2	T3
U1-SN (degrees)	2.2°		
Facial Convexity (G'-Sn-Po') (degrees)	0.8°	0.9°	0.9°
Mx Unit Length (Co-ANS)(mm)		2.4mm	
Mx/Md Diff (Co-Gn – Co-ANS) (mm)		1.6mm	
IMPA (L1-MP)(degrees)		2.6°	1.8°
Wits (mm)			2.1mm

The important variables to consider in Class II correction for the table above would include all but the facial convexity. These errors indicate that the cephalometric measurements have an accuracy level of 2.2 degrees for U1-SN at T1, 1.8 degrees for L1-MP at T3, and 2.1mm for Wits at T3. I can only conjecture the reasons for these errors. Oftentimes, when tracing the conventional lateral cephalograms, it was difficult to accurately locate the incisal tips and apices of the maxillary and mandibular incisors, which would have inevitably introduced error into the U1-SN and IMPA measurements.

Moreover, Yu et al[44] has stated A point is difficult to locate, which would contribute to an error in the Wits appraisal. Condylion, as anyone can attest to, is also a very difficult point to plot accurately. Lastly, Kazandjian et al[45] noted that it's difficult to locate ANS since it's of subjective location and low radiopacity, providing a rationale for the significant Dahlberg error seen in the maxillary unit length and maxillary/mandibular unit length difference.

Regardless of these random errors, the author can assert with reasonable confidence that, in general, the tracings were accurate as there were only several variables out of the 29 that exhibited error and that error was relatively small.

Skeletal Anterior-Posterior Component

Although this study's focus is on post-retention changes of treatment with the Forsus™, knowledge of the intra-treatment changes may help in understanding the changes seen during the post-retention period. During T1-T2, SNA decreased by 0.9±1.5 degrees, SNB increased 0.9±1.4 degrees, and ANB decreased 1.8±1.2 degrees (Figure 4, Table 15). Franchi et al[30] in a Forsus

study saw a decrease in SNA of 1.6±1.4 degrees, an increase in SNB of 0.3±1.4 degrees, and a 1.9±1.2 degree decrease in ANB. Lerstol et al[25] and Janson et al,[46] using combination headgear-activator therapy, revealed a similar range of SNA decrease, SNB increase, and ANB decrease, Heinig[27] using a Forsus spring showed a similar result in SNB, and lastly, Miller et al,[47] in his Forsus™ study, showed a similar range of decrease in ANB. The SNA decrease could suggest a restraining effect on the sagittal growth of the maxilla and the SNB increase is likely consequent to normal mandibular growth.

From T2-T3, SNA increased by 0.9±1.5 degrees, SNB increased by 1.0±1.4 degrees, and ANB essentially stayed the same with a 0.1±1.2 degrees increase (Figures 5,6). The SNA and SNB increase can be consequent to normal growth and development. Both the maxilla and mandible were able to resume their natural growth pattern without contributing much to a significant change in the anterior-posterior relationship discrepancy as noted by the minimal average increase in ANB. In addition, as seen in Table 16, the post-retention changes in SNA, SNB, and ANB are generally in agreement with the range of changes seen in other literature.

Mandibular Unit Length

During the post-retention period, the mandibular unit length continued to increase. The mean age at treatment completion was 14.7±1.2 years and the mean age at the completion of the retention period was 16.9±1.4 years so one would expect that this increase could be attributed to normal growth. Since there are presently no other Forsus™ post-retention/stability studies, it is not feasible to

make comparisons of the post-treatment relapse/stability measures. However, considering the literature that examined post-retention changes, or in other words stability, following other functional appliance therapy, some differences or similarities in their results can be seen. Francisconi et al[40] looked at Class II stability (10 year post-retention period) with the Bionator followed by fixed appliances. Similar to this study in that there was no control group, a mean 4.26mm increase was noted in the mandibular unit length as compared to a 3.0mm increase in this study. As stated by Francisconi, this can contribute to stability of Class II correction.

Malta et al[41] in evaluating the long-term dentoskeletal effects (6 years post treatment retention period) induced by bionator therapy found a net average 3.3mm increase in mandibular unit length compared with untreated Class II controls. Lastly, Freeman et al,[12] who conducted a controlled study, looked at the long term treatment effects (5 years post-treatment) with the FR-2 appliance of Frankel and found a statistically significant long-term increase of 3mm in mandibular length compared to untreated Class II controls. This is equivalent to the mean increase observed in this study.

<u>Wits</u>

From T1-T2, the Wits decreased by 3.1±3.4mm, which is in accordance with the ranges seen in Franchi's 2011 study with the Forsus™ and Malta's 2010 study with the Bionator (Figure 7, Table 17).

On the other hand, during the post-retention period, the Wits increased by a mean of 0.6mm (Figure 8). This is in good agreement with research carried out

by Malta et al,[41] which showed a 0.5mm mean increase during the post-treatment observation period (Table 18). The increase in Wits seen in this study could be due to a continued lagging behind of mandibular growth relative to maxillary growth, which would result in A point being even further in front than B point and thus, resulting in an increased Wits.

Skeletal Vertical Relationship

During the intra-treatment period, FMA (Frankfort Horizontal-Mandibular Plane) decreased by 0.5±2.4 degrees and SN-MP (Sella·Nasion-Mandibular Plane) remained the same (Figure 9). This is in agreement with other studies by Franchi et al and Janson et al (Table 19).[30,46] The decrease in FMA could be due to the intrusive vectors on the maxillary molars imposed by the Forsus™, which would cause an autorotation and therefore, lead to slight closure of the mandibular plane angle.

During the post-treatment observation period (T2-T3), FMA decreased 0.6±1.9 degrees and SN-MP decreased 1.0±1.8 degrees (Figure 10,11). Schudy's article on post-treatment craniofacial growth[48] states that growth that usually takes place in the post-treatment period is characterized by a mandibular counterclockwise rotation in response to the vertical redirection of condylar growth, thus resulting in decreased FMA and SN-MP angles. These post-retention changes are in good agreement with other studies using the Bionator, Activator or combination Activator-Headgear (Table 20).[25,30,46] One thing to note is that in the Franchi et al[35] study, there was a 2.7±2.5 degree decrease. It is plausible that the vast range of values were caused by the experimental group

containing individuals who were treated early (i.e. before puberty) and those who were treated at puberty because it was shown that either the activator or bionator used at the pubertal phase produced greater vertical changes.[35]

Maxillary and Mandibular Dentoalveolar Components

From T1-T2, this study showed a slight decrease in U1-SN and an increase in U1-PP and IMPA. Specifically, the mandibular incisors proclined 4.5±6.7 degrees (Figure 12). The proclination occurring with the Forsus™ appliance can be seen with other functional appliances. In this study, this effect is expected due to the mesializing force vector exerted on the lower incisors by the appliance and corresponds well to that of other studies such as Franchi et al, Jones et al, and Heinig et al, which showed increases of 6.1±6.3, 6.3±6.7, and 9.6 degrees respectively (Table 21).[4,27,30]

During the retention period, there were increases in U1-SN and U1-PP of 0.7±3.7 and 0.1±3.5 degrees respectively while IMPA decreased by 1.6±4.0 degrees (Figure 13,14). Multiple factors could have contributed to these changes and they are as follows:

- Inadequate, or lack thereof, wear of the maxillary Hawley retainer could have altered the inclinations of the upper incisors.
- Though all patients were bonded with a mandibular 3-3 fixed retainer, the lower incisor could have uprighted slightly through movement of the roots facially or the individual could have broken the retainer.

- Research by Elms et al[49] indicated that the more mandibular incisors are labially tipped during treatment (i.e. 5 degrees), the less their stability in the post-treatment period. The same applies for upper incisor proclination during the post-retention period, but in this case, there weren't significant changes during treatment on average in the inclination of the upper incisors.

One could also note the large standard deviations present in U1-SN and U1-PP. This is because there was such a large range of values for each. For instance, the minimum-maximum value for U1-SN change was -8.6 to 7.1 with the median being 1. The values were very scattered; nevertheless, an average 0.7 degree increase is minimal at worst considering the average final U1-SN was 104.2 degrees.

Finally, similar to the other cephalometric variables noted, U1-SN, U1-PP, and IMPA had values that were concordant with the range found in other studies (Table 22).[25,35,46] Franchi et al,[35] on the other hand, showed an increase in IMPA which could be due to a different retention protocol. Unfortunately, one can only surmise this to be the case because a retention protocol was not addressed in the article. In addition, L1-NB (the bodily position of the lower incisor) showed a change of 0.5±0.9mm, similar to other studies by Janson et al[46] with the headgear-activator combination and Pancherz with Herbst treatment.[36] Both studies retained their treatment groups with a 3-3 bonded lingual retainer similar to the retention protocol used by Dr. Alvetro. The relative stability of the bodily

position and inclination of the lower incisors could be attributed to the mandibular bonded lingual retainer that Dr. Alvetro placed in all of her completed cases.

Dentoalveolar Relationships

Overjet and overbite decreased during treatment (T1-T2) with the Forsus™. In this study's sample, net reduction of 4.5mm for overjet and 3.0mm for overbite was noted (Figure 15). The experimental group began with an overjet and overbite of 7.1±2.1mm and 4.5±2.0mm respectively, which indicate characteristics of a Class II Div 1 malocclusion; that is, excessive overjet with a deep bite. Reduction in overjet and overbite would be expected due to a combination of normal mandibular growth, slight retroclination of the upper incisors, and proclination of the lower incisors noted previously. This notion is further bolstered by Drage et al, who stated that overjet relapse was due to the aforementioned factors.[50]

Similar to this study, Franchi et al reported a net reduction of 5.5mm for overjet and a 2.4mm reduction in the overbite with the Forsus™.[30] Lerstol et al reported a 4.4mm reduction in overjet and 2.3mm reduction in overbite using activator-headgear treatment.[25] Francisconi et al showed that using the Bionator caused overjet to decrease by a mean of 5.4mm and overbite by 1.9mm.[40] Although different functional appliances were used, all studies showed similar values in overjet and overbite reduction.

During the post-treatment retention period (T2-T3), overjet and overbite increased by 0.8±0.7mm and 0.9±1.0mm respectively (Figure 16,17). The increase in overjet could be due to several effects: an uprighting of the lower

incisors, increased proclination of the upper incisors, and quite possibly, the patient may have shifted their mandible to their natural, more retruded position. The Forsus™ acts to posture the mandible forward and once the appliance is removed after an extended period of time, approximately 5 months in this study, the patient may gradually slip the mandible to his/her more retruded, natural position. Finally, yet another factor contributing to a post-retention increase in overbite and overjet can result from a redeepening of the curve of Spee, which is oftentimes seen in Class II Div 1 patients after they are leveled out.

With regards to overbite, the literature abounds with evidence of overbite increase following successful Class II treatment. Fidler et al[51] stated that a post-retention increase in overbite is often observed. In his study, he had an average 14 year retention period. Uhde et al concluded from his Class II sample that overbite tended to increase after treatment with the amount of overbite increase statistically correlated to the amount of overbite reduction during treatment.[52] As the overbite was increased after treatment, the overjet also tended to increase. This was evident in this study.

Here again, the overjet and overbite changes in this study agree well with the ranges mentioned in other literature. For instance, Lerstol et al[25] noted an increase of 0.1 ± 1.7mm and 0.3 ± 0.7mm in overjet and overbite respectively along with Janson et al who stated an increase of 0.4 ± 1.3mm and 1.1 ± 1.1mm in overjet and overbite (Table 23).[46]

Limitations of Study

First, in order to differentiate post-retention changes attributed either to dental instability from those due to normal growth and development, a comparison of this study's experimental group to that of an untreated control sample with the same malocclusion would have enabled us to do so. Due to this limitation, the statistics utilized made it unreasonable to claim "statistically" significant differences between the measurements in the different time periods.

Second, cone beam computed tomography (CBCT) lateral cephalograms provide precise 1:1 scale imaging, eliminate the magnification errors seen in conventional ones, and the landmarks are easier to detect on a cone beam cephalogram compared to a conventional one. Moreover, Navarro et al noted that there was greater reliability obtained from the CBCT scans.[53] Having said that, since three conventional lateral cephalograms were taken for all time periods per patient, it would be impractical and perhaps unethical to subject patients to an unnecessary amount of excess radiation by taking 3 CBCTs merely for research purposes.

Third, the post-retention period was shorter in duration than other cited studies, which had an average retention period of 6 years. Perhaps, taking post-retention radiographs about 6-7 years out might serve to further elucidate the post-retention changes observed and obviate the need for a control group.

Lastly, it would have been beneficial to look at casts of the sample's post-treatment and post-retention results, which would have enabled the author to utilize the PAR (peer assessment rating) index. The PAR Index is a single score

that estimates how far a case deviates from normal alignment and occlusion.[54] The difference in scores between the post-treatment and post-retention casts can be used as an effective means to evaluate relapse and set a threshold value in determining whether the post-retention period was stable. Indeed, this would have been another effective tool to analyze the stability of the results.

CONCLUSIONS

Within the parameters of this study, the following conclusions can be drawn:

- The retention protocol utilized by Dr. Lisa Alvetro (i.e. placement of a fixed mandibular 3-3 lingual retainer following treatment with Forsus™) allowed for a relatively stable inclination on the mandibular incisors.
- Since there was no appliance allowing for a restraining effect on the sagittal position of the maxilla nor an advancing force on the mandible during the post-retention period, the SNA and SNB increases during post-retention are most likely due to continued normal growth
    - These changes were nearly identical to each other; therefore, the post-retention skeletal anteroposterior relationship was maintained.
- The null hypothesis in this study was rejected. That is, there were indeed changes that occurred during the retention phase, though most were small and clinically insignificant.

Appendix: Raw Data

Intraexaminer Error (T1)

	T1 First Measurement		Second Measurement		paired t-test (p-value)	Dahlberg Error
	mean	SD	mean	SD		
SNA (°)	81.7	3.8	81.4	3.9	>0.05	0.7
A-Nperp (mm)	-2.0	3.1	-2.2	3.0	>0.05	1.0
Mx Unit Length (Co-ANS) (mm)	85.6	6.2	86.5	6.2	>0.05	1.4
SNB (°)	76.4	3.4	76.0	3.5	>0.05	0.6
B-Nperp (mm)	-11.6	4.6	-11.8	4.4	>0.05	1.5
Pog-Nperp (mm)	-10.9	5.3	-11.2	5.0	>0.05	1.8
Mand Unit Length (Co-Gn) (mm)	107.2	5.9	107.1	5.0	>0.05	1.5
ANB (°)	5.4	1.9	5.3	1.9	>0.05	0.5
Wits (mm)	2.3	3.2	1.1	3.2	>0.05	1.7
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	21.5	4.5	20.6	4.0	>0.05	1.6
FH-SN (°)	6.0	2.1	6.3	2.0	>0.05	1.1
FMA (MP-FH) (°)	27.2	5.2	27.3	5.0	>0.05	1.3
LFH/TFH (ANS-Me:N-Me) (%)	54.4	2.6	54.5	2.9	>0.05	0.8
MP-SN (°)	33.3	5.3	33.7	5.6	>0.05	8.8
U1-SN (°)	104.7	9.7	102.9	9.0	≤0.05	2.2
U1-Palatal Plane (°)	110.3	9.4	108.4	8.5	>0.05	2.5
U1-PP (UADH) (mm)	26.9	2.9	27.2	2.8	>0.05	0.7
U6-PP (UPDH) (mm)	19.2	1.8	18.8	1.9	>0.05	0.5
U1-NA (mm)	4.2	3.1	4.3	3.0	>0.05	0.9
L1-NB (mm)	4.0	2.5	4.0	2.5	>0.05	0.3
IMPA (L1-MP) (°)	92.9	8.8	94.4	9.1	>0.05	1.7
L1-MP (LADH) (mm)	37.5	3.6	37.6	3.4	>0.05	0.5
L6-MP (LPDH) (mm)	26.2	3.0	26.2	2.8	>0.05	0.7
Overjet (mm)	7.2	2.3	7.3	2.4	>0.05	0.4
Overbite (mm)	4.9	2.0	5.2	2.0	>0.05	0.6
Interincisal Angle (°)	129.1	11.8	130.0	11.0	>0.05	2.4
Facial Convexity (G'-Sn-Po') (°)	17.5	4.2	16.8	4.2	≤0.05	0.8
Upper Lip-S Line (mm)	1.8	1.6	1.9	1.6	>0.05	0.4
Lower Lip-S Line (mm)	1.3	1.8	1.2	1.8	>0.05	0.4

Intraexaminer Error (T2)

	T2 First Measurement		Second Measurement		paired t-test (p-value)	Dahlberg Error
	mean	SD	mean	SD		
SNA (°)	80.9	4.5	80.9	4.4	>0.05	0.7
A-Nperp (mm)	-2.1	3.6	-1.8	3.8	>0.05	1.1
Mx Unit Length (Co-ANS) (mm)	86.5	5.3	88.8	5.2	≤0.05	2.4
SNB (°)	77.3	3.9	77.2	4.0	>0.05	0.4
B-Nperp (mm)	-9.4	4.9	-9.2	4.9	>0.05	1.6
Pog-Nperp (mm)	-8.3	5.4	-8.1	5.2	>0.05	1.8
Mand Unit Length (Co-Gn) (mm)	113.3	6.0	114.0	5.4	>0.05	2.2
ANB (°)	3.7	2.7	3.8	2.5	>0.05	0.5
Wits (mm)	-1.4	3.1	-0.5	2.1	>0.05	1.7
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	26.7	5.2	25.1	4.9	≤0.05	1.6
FH-SN (°)	7.1	2.6	7.3	2.5	>0.05	1.0
FMA (MP-FH) (°)	26.3	5.0	26.0	5.2	>0.05	1.1
LFH/TFH (ANS-Me:N-Me) (%)	54.9	2.9	55.3	2.8	>0.05	0.6
MP-SN (°)	33.4	5.7	33.3	5.7	>0.05	0.6
U1-SN (°)	104.1	8.7	102.8	7.4	>0.05	1.7
U1-Palatal Plane (°)	110.4	8.2	109.1	7.1	>0.05	1.9
U1-PP (UADH) (mm)	27.2	3.1	28.0	2.9	>0.05	1.0
U6-PP (UPDH) (mm)	20.5	2.2	20.8	2.6	>0.05	1.5
U1-NA (mm)	3.2	2.9	3.1	2.7	>0.05	0.7
L1-NB (mm)	5.7	2.1	5.8	2.1	>0.05	0.3
IMPA (L1-MP) (°)	96.7	6.2	98.7	5.6	≤0.05	2.6
L1-MP (LADH) (mm)	37.9	3.5	38.0	3.3	>0.05	0.7
L6-MP (LPDH) (mm)	29.1	3.1	29.1	2.8	>0.05	0.7
Overjet (mm)	2.6	0.5	2.7	0.5	>0.05	0.2
Overbite (mm)	1.6	0.8	1.7	0.8	>0.05	0.5

Interincisal Angle (°)	124.9	10.6	125.2	8.2	>0.05	4.1
Facial Convexity (G'-Sn-Po') (°)	15.2	5.0	14.4	5.1	≤0.05	0.9
Upper Lip-S Line (mm)	0.1	2.0	0.2	2.1	>0.05	0.3
Lower Lip-S Line (mm)	0.7	1.9	1.0	1.9	>0.05	0.4

Intraexaminer Error (T3)

	T3					
	First Measurement		Second Measurement		paired t-test (p-value)	Dahlberg Error
	mean	SD	mean	SD		
SNA (°)	81.6	4.2	81.9	4.2	>0.05	0.6
A-Nperp (mm)	-1.7	3.5	-1.9	3.4	>0.05	1.4
Mx Unit Length (Co-ANS) (mm)	88.9	6.2	90.1	5.4	>0.05	2.4
SNB (°)	78.2	4.2	78.2	4.2	>0.05	0.4
B-Nperp (mm)	-9.1	5.3	-8.9	5.6	>0.05	1.6
Pog-Nperp (mm)	-7.8	5.9	-7.8	6.3	>0.05	1.7
Mand Unit Length (Co-Gn) (mm)	115.9	6.8	115.9	6.0	>0.05	2.4
ANB (°)	3.7	2.7	3.8	2.3	>0.05	0.5
Wits (mm)	0.2	3.3	-1.7	2.9	≤0.05	2.1
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	27.0	5.6	25.8	5.3	>0.05	1.6
FH-SN (°)	6.4	2.4	6.5	2.2	>0.05	1.0
FMA (MP-FH) (°)	25.9	5.3	25.4	5.6	>0.05	1.1
LFH/TFH (ANS-Me:N-Me) (%)	55.5	2.4	55.6	2.9	>0.05	0.8
MP-SN (°)	32.2	6.2	31.9	6.1	>0.05	0.8
U1-SN (°)	104.6	8.4	104.0	7.8	>0.05	1.3
U1-Palatal Plane (°)	110.3	7.0	109.3	7.1	>0.05	1.6
U1-PP (UADH) (mm)	28.3	2.8	28.7	3.1	>0.05	1.0
U6-PP (UPDH) (mm)	22.1	2.4	21.2	1.9	>0.05	1.2
U1-NA (mm)	3.5	2.7	0.4	2.6	>0.05	0.7
L1-NB (mm)	5.2	2.4	5.4	2.3	>0.05	0.3
IMPA (L1-MP) (°)	95.7	6.6	97.2	6.2	≤0.05	1.8
L1-MP (LADH) (mm)	39.1	3.7	38.9	3.3	>0.05	0.7
L6-MP (LPDH) (mm)	29.4	2.8	30.0	2.7	>0.05	1.2
Overjet (mm)	3.5	0.8	3.5	0.8	>0.05	0.3
Overbite (mm)	2.5	1.0	2.8	1.1	>0.05	0.4

Interincisal Angle (°)	127.5	8.9	126.9	8.4	>0.05	1.6
Facial Convexity (G'-Sn-Po') (°)	14.7	5.4	13.9	5.8	≤0.05	0.9
Upper Lip-S Line (mm)	-0.7	2.6	-0.6	2.5	>0.05	0.3
Lower Lip-S Line (mm)	-0.3	2.3	-0.2	2.5	>0.05	0.4

Cephalometric Raw Data: Mean and SD (All Time Periods and T1)

	All			T1		
	n	mean	SD	n	mean	SD
SNA (°)	119	81.1	3.7	40	81.4	3.8
A-Nperp (mm)	120	-2.05	3.3	40	-1.9	3.0
Mx Unit Length (Co-ANS) (mm)	120	87.0	5.6	40	85.6	5.6
SNB (°)	120	76.9	3.7	40	76.0	3.1
B-Nperp (mm)	120	-10.2	4.7	40	-11.6	4.1
Pog-Nperp (mm)	120	-9.3	5.5	40	-11.1	4.9
Mand Unit Length (Co-Gn) (mm)	120	111.7	8.0	40	106.7	6.7
ANB (°)	120	4.2	2.4	40	5.5	1.9
Wits (mm)	120	0.2	3.3	40	2.1	3.1
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	120	24.7	5.8	40	21.1	4.4
FH-SN (°)	120	6.7	2.4	40	6.4	2.7
FMA (MP-FH) (°)	120	26.9	4.8	40	27.5	4.7
LFH/TFH (ANS-Me:N-Me) (%)	120	54.6	2.7	40	54.0	2.7
MP-SN (°)	120	33.6	5.2	40	34.0	4.9
U1-SN (°)	120	103.9	7.7	40	103.9	8.2
U1-Palatal Plane (°)	120	110.8	7.6	40	110.6	8.1
U1-PP (UADH) (mm)	119	27.3	3.1	40	26.6	3.0
U6-PP (UPDH) (mm)	120	20.7	2.7	40	19.3	2.2
U1-NA (mm)	120	3.6	2.5	40	3.9	2.7
L1-NB (mm)	120	5.1	2.4	40	4.0	2.2
IMPA (L1-MP) (°)	120	95.5	7.3	40	93.0	7.6
L1-MP (LADH) (mm)	120	38.0	3.3	40	37.3	3.3
L6-MP (LPDH) (mm)	120	28.2	3.0	40	26.2	2.6
Overjet (mm)	120	4.3	2.4	40	7.1	2.1
Overbite (mm)	120	2.8	1.9	40	4.5	2.0

Interincisal Angle (°)	120	126.8	10.2	40	129.2	10.6
Facial Convexity (G'-Sn-Po') (°)	120	16.5	5.1	40	18.1	4.3
Upper Lip-S Line (mm)	119	0.3	2.4	40	1.7	2.1
Lower Lip-S Line (mm)	119	0.9	2.2	40	1.5	2.1

Cephalometric Raw Data: Mean and SD (T1 and T2)

	T2			T3		
	n	mean	SD	n	mean	SD
SNA (°)	40	80.5	4.0	39	81.2	3.8
A-Nperp (mm)	40	-2.4	3.5	40	-1.8	3.5
Mx Unit Length (Co-ANS) (mm)	40	86.5	4.7	40	88.9	6.0
SNB (°)	40	76.9	3.7	40	77.8	4.0
B-Nperp (mm)	40	-10.0	4.7	40	-9.1	5.1
Pog-Nperp (mm)	40	-8.9	5.3	40	-7.9	5.8
Mand Unit Length (Co-Gn) (mm)	40	112.7	6.4	40	115.8	8.1
ANB (°)	40	3.6	2.3	40	3.6	2.4
Wits (mm)	40	-1.0	3.0	40	-0.5	3.2
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	40	26.2	5.4	40	27.0	5.8
FH-SN (°)	40	7.0	2.6	40	6.7	2.5
FMA (MP-FH) (°)	40	26.9	4.7	40	26.2	4.9
LFH/TFH (ANS-Me:N-Me) (%)	40	54.6	2.7	40	55.2	2.5
MP-SN (°)	40	34.0	5.0	40	33.0	5.7
U1-SN (°)	40	103.5	7.8	40	104.2	7.3
U1-Palatal Plane (°)	40	110.8	8.0	40	111.0	6.8
U1-PP (UADH) (mm)	39	27.2	3.2	40	28.2	3.1
U6-PP (UPDH) (mm)	40	20.7	2.4	40	22.1	2.7
U1-NA (mm)	40	3.4	2.5	40	3.7	2.3
L1-NB (mm)	40	5.8	2.2	40	5.4	2.4
IMPA (L1-MP) (°)	40	97.5	6.9	40	95.9	7.0
L1-MP (LADH) (mm)	40	37.6	3.1	40	39.0	3.4
L6-MP (LPDH) (mm)	40	28.9	2.8	40	29.5	2.8
Overjet (mm)	40	2.6	0.6	40	3.4	0.7
Overbite (mm)	40	1.5	1.0	40	2.4	1.0

Interincisal Angle (°)	40	124.4	10.5	40	126.7	9.1
Facial Convexity (G'-Sn-Po') (°)	40	15.8	5.3	40	15.5	5.3
Upper Lip-S Line (mm)	40	-0.1	2.0	39	-0.8	2.4
Lower Lip-S Line (mm)	40	1.0	2.0	39	0.1	2.3

Cephalometric Raw Data: Repeated Measures ANOVA

	p-value	method: repeated measures ANOVA
SNA (°)	>0.05	Means are not significantly different
A-Nperp (mm)	>0.05	Means are not significantly different
Mx Unit Length (Co-ANS) (mm)	≤0.05	Means are significantly different
SNB (°)	≤0.05	Means are significantly different
B-Nperp (mm)	≤0.05	Means are significantly different
Pog-Nperp (mm)	≤0.05	Means are significantly different
Mand Unit Length (Co-Gn) (mm)	≤0.05	Means are significantly different
ANB (°)	≤0.05	Means are significantly different
Wits (mm)	≤0.05	Means are significantly different
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	≤0.05	Means are significantly different
FH-SN (°)	>0.05	Means are not significantly different
FMA (MP-FH) (°)	>0.05	Means are not significantly different
LFH/TFH (ANS-Me:N-Me) (%)	≤0.05	Means are significantly different
MP-SN (°)	>0.05	Means are not significantly different
U1-SN (°)	>0.05	Means are not significantly different
U1-Palatal Plane (°)	>0.05	Means are not significantly different
U1-PP (UADH) (mm)	≤0.05	Means are significantly different
U6-PP (UPDH) (mm)	≤0.05	Means are significantly different
U1-NA (mm)	>0.05	Means are not significantly different
L1-NB (mm)	≤0.05	Means are significantly different
IMPA (L1-MP) (°)	≤0.05	Means are significantly different
L1-MP (LADH) (mm)	≤0.05	Means are significantly different
L6-MP (LPDH) (mm)	≤0.05	Means are significantly different
Overjet (mm)	≤0.05	Means are significantly different
Overbite (mm)	≤0.05	Means are significantly different

Interincisal Angle (°)	>0.05	Means are not significantly different
Facial Convexity (G'-Sn-Po') (°)	≤0.05	Means are significantly different
Upper Lip-S Line (mm)	≤0.05	Means are significantly different
Lower Lip-S Line (mm)	≤0.05	Means are significantly different

Cephalometric Raw Data: Mean and SD (Differences for All Time Periods)

	Difference T1 to T2			Difference T2 to T3			Difference T1 to T3		
	mean	SD	p-value	mean	SD	p-value	mean	SD	p-value
SNA (°)	0.9	1.5	>0.05	-0.9	1.9	>0.05	0.1	1.9	>0.05
A-Nperp (mm)	0.5	2.2	>0.05	-0.6	2.2	>0.05	-0.1	2.2	>0.05
Mx Unit Length (Co-ANS) (mm)	-0.8	3.4	>0.05	-2.4	2.8	≤0.05	-3.2	4.1	≤0.05
SNB (°)	-0.9	1.4	≤0.05	-1.0	1.3	≤0.05	-1.9	2.0	≤0.05
B-Nperp (mm)	-1.6	3.0	>0.05	-0.9	3.2	>0.05	-2.5	3.0	≤0.05
Pog-Nperp (mm)	-2.1	3.3	≤0.05	-1.0	3.6	>0.05	-3.2	3.5	≤0.05
Mand Unit Length (Co-Gn) (mm)	-6.0	3.8	≤0.05	-3.0	3.6	≤0.05	-9.1	5.3	≤0.05
ANB (°)	1.8	1.2	≤0.05	0.1	0.9	>0.05	1.9	1.4	≤0.05
Wits (mm)	3.1	3.4	≤0.05	-0.6	3.5	>0.05	2.5	4.1	≤0.05
Mx/Md Diff (Co-Gn - Co-ANS) (mm)	-5.2	2.8	≤0.05	-0.7	3.0	>0.05	-5.9	3.6	≤0.05
FH-SN (°)	-0.6	2.0	>0.05	0.3	1.7	>0.05	-0.3	1.9	>0.05
FMA (MP-FH) (°)	0.5	2.4	>0.05	0.6	1.9	>0.05	1.2	2.4	>0.05
LFH/TFH (ANS-Me:N-Me) (%)	-0.6	1.6	>0.05	-0.6	0.9	≤0.05	-1.2	1.6	≤0.05
MP-SN (°)	-0.005	2.0	>0.05	1.0	1.8	>0.05	1.0	2.7	>0.05
U1-SN (°)	0.3	7.2	>0.05	-0.7	3.7	>0.05	-0.4	6.1	>0.05
U1-Palatal Plane (°)	-0.3	7.5	>0.05	-0.1	3.5	>0.05	-0.4	5.8	>0.05
U1-PP (UADH) (mm)	-0.6	2.0	>0.05	-1.0	1.3	≤0.05	-1.7	1.9	≤0.05
U6-PP (UPDH) (mm)	-1.4	1.4	≤0.05	-1.4	1.6	≤0.05	-2.8	2.1	≤0.05
U1-NA (mm)	0.6	2.3	>0.05	-0.3	1.2	>0.05	0.2	2.1	>0.05
L1-NB (mm)	-1.8	1.4	≤0.05	0.5	0.9	>0.05	-1.3	1.5	≤0.05
IMPA (L1-MP) (°)	-4.5	6.7	≤0.05	1.6	4.0	>0.05	-2.9	6.5	>0.05
L1-MP (LADH) (mm)	-0.3	1.6	>0.05	-1.4	1.4	≤0.05	-1.7	2.1	≤0.05
L6-MP (LPDH) (mm)	-2.6	1.8	≤0.05	-0.6	1.4	>0.05	-3.3	1.8	≤0.05
Overjet (mm)	4.5	2.2	≤0.05	-0.8	0.7	≤0.05	3.7	1.9	≤0.05
Overbite (mm)	3.0	2.0	≤0.05	-0.9	1.0	≤0.05	2.1	1.8	≤0.05
Interincisal Angle (°)	4.8	10.3	>0.05	-2.3	7.1	>0.05	2.5	9.6	>0.05
Facial Convexity (G'-Sn-Po') (°)	2.3	4.4	>0.05	0.3	3.7	>0.05	2.6	3.1	≤0.05
Upper Lip-S Line (mm)	1.8	1.6	≤0.05	0.7	1.1	≤0.05	2.5	1.6	≤0.05
Lower Lip-S Line (mm)	0.5	1.5	>0.05	0.9	1.0	≤0.05	1.4	1.5	≤0.05

Literature Cited

1) Proffit, WR, Fields, Fields HW, Sarver D. Contemporary Orthodontics. 5th ed. St. Louis: Mosby; 2013.
2) Proffit WR, Fields HW, Moray LJ. Prevalence of malocclusion and orthodontic treatment need in the United States (estimates from the NHANES-III survey). Int J Adult Orthod Orthognath Surg. 1998;13:97-106.
3) McNamara Jr JA. Components of Class II malocclusion in children 8-10 years of age. Angle Orthod. 1981;51:177-202.
4) Jones G, Buschang PH, Kim KB, Oliver DR. Class II non-extraction patients treated with the Forsus Fatigue Resistant Device versus intermaxillary elastics. Angle Orthod. 2008 Mar; 78(2):332-8.
5) Mihalik CA, Proffit WR, Phillips C. Long-term follow-up of Class II adults treated with orthodontic camouflage: A comparison with orthognathic surgery outcomes. Am J Orthod Dentofacial Orthop. 2003;123(3): 266-278.
6) Chhibber A, Upadhyay M, Uribe F, Nanda R. Long-term stability of Class II correction with the Twin Force Bite Corrector. J Clin Orthod. 2010 Jun;44(6):363-76.
7) Janson G, Araki J, Camardella LT. Posttreament stability in Class II nonextraction and maxillary premolar extraction protocols. Orthodontics: The Art and Practice of Dentofacial Enhancement. 2012;13(1):12-21.
8) Graber TM, Vanarsdall RL, Vig K WL. Orthodontics: Current Principles and Techniques. 5th ed. St. Louis: Mosby; 2012.
9) Poulton DR. The influence of extraoral traction. Am J Orthod. 1967;53:8-18.
10) Wieslander L. Early or late cervical traction therapy of Class II malocclusion in the mixed dentition. Am J Orthod. 1975;67:432-439.
11) Faltin Jr K, Faltin RM, Baccetti T, Franchi L, Ghiozzi B, McNamara Jr JA. Long-term effectiveness and treatment timing for Bionator therapy. Angle Orthod. 2003;73:221-230.
12) Freeman DC, McNamara Jr JA, Baccetti T, Franchi L. Long-term treatment effects of the FR-2 appliance of Frankel. Am J Orthod Dentofac Orthop. 2008;133:513-524.
13) McNamara JA, Howe RP, Dischinger TG. A comparison of the Herbst and Frankel appliances in the treatment of Class II malocclusion. Am J Orthod Dentofacial Orthop 1990;98:134-144.
14) Cozza P, Baccetti T, Franchi L, DeToffol L, McNamara JA Jr. Mandibular changes produced by functional appliances in Class II malocclusion: A systematic review. Am J Orthod Dentofacial Orthop 2006;129:1-11.
15) Antonarakis GS, Kiliaridis S. Maxillary molar distalization with noncompliance intramaxillary appliances in class II malocclusion. A systematic review. Angle Orthod 2008 Nov;78(6):1133-40.
16) Pancherz H. The mechanism of Class II correction in Herbst appliance treatment. Am J Ortho 1982;82:104-113.

17) Karacay S, Akin E, Olmez H, Gurton AU, and Sagdic. Forsus Nitinol Flat Spring and Jasper Jumper Corrections of Class II division 1 Malocclusions. Angle Orthod. 2006 Jul;76(4):666-72.
18) Nayak UK, Goyal V. Treatment of division II malocclusion in young adult with Forsus^{TM} fatigue-resistant device. Indian Journal of Dental Research. Mar/Apr2012,Vol. 23 Issue 2, p.289-291.
19) McNamara JA Jr. Neuromuscular and skeletal adaptations to altered function in the orofacial region. Am J Orthod. 1973 Dec;64(6):578-606.
20) Tulloch JF, Proffit WR, Phillips C. Outcomes in a 2-phase randomized clinical trial of early Class II treatment. Am J Orthod Dentofacial Orthop. 2004 Jun;125(6):657-67.
21) Nanda R, Burzin J, Kim JM. 1993. Factors influencing the stability of orthodontically treated dentitions. In: Hosl E, Bladauf A (eds). Retention and long-term stability**.** 8th International Conference for Orthodontists Huthig, Heidelberg, pp. 41-46.
22) Ormiston JP, Huang GJ, Little RM, Decker JD, Seuk GD. Retrospective analysis of long-term stable and unstable orthodontic treatment outcomes. Am J Orthod Dentofacial Orthop. 2005 Nov;128(5):568-74.
23) Bock NC, Ruf S. Post-treatment occlusal changes in Class II division 2 subjects treated with the Herbst appliance. European Journal of Orthodontics. Dec 2008, Vol. 30 Issue 6, p.606-613.
24) Bock NC, Von Bremen J, Ruf S. Occlusal stability of adult Class II Division 1 treatment with the Herbst appliance. Am J Orthod Dentofacial Orthop. Aug 2010, Vol. 138 Issue 2, p146-151.
25) Lerstol M, Oystein T, Vandevska-Radunovic V. Long-term stability of dentoalveolar and skeletal changes after activator–headgear treatment. European Journal of Orthodontics. Feb2010, Vol. 32 Issue 1, p28-35.
26) Bowman A, Saltaji H, Flores-Mir C, Preston B, Tabbaa S. Patient experiences with the Forsus Fatigue Resistant Device. Angle Orthodontist. May2013, Vol. 83 Issue 3, p437-446.
27) Heinig N, Goz G. Clinical Application and Effects of the Forsus™ Spring A Study of a New Herbst Hybrid. J Orofac Orthop. 2001 Nov;62(6):436-50.
28) Vijayalakshmi, P. S., Veereshi, A. S. Management of Severe Class II Malocclusion with Fixed Functional Appliance**:** Forsus**.** Journal of Contemporary Dental Practice.May/Jun2011, Vol. 12 Issue 3, p216-220.
29) Belma I. Aslan, Ebru Kucukkaraca, Cagri Turkoz, and Mufide Dincer. Treatment effects of the Forsus Fatigue Resistant Device used with miniscrew anchorage. Angle Orthod. 2013 Jun 17.
30) Franchi L, Alvetro L, Giuntini V, Masucci C, Defraia E, Baccetti T. Effectiveness of comprehensive fixed appliance treatment used with the Forsus Fatigue Resistant Device in Class II patients. Angle Orthod. 2011 Jul;81(4):678-83.
31) Xiong H, Hagg U, Tang G-H, Rabie ABM, Robinson W. The effect of continuous bite jumping in adult rats: a morphological study. Angle Orthod 2004;74:86-92.

32) Stockli PW, Willert HW. Tissue Reactions in the Temporomandibular Joint Resulting from Anterior Displacement of the Mandible in the Monkey. Am J Orthod 1971; 60:142-155.
33) Baccetti T, Franchi L, Ratner L. McNamara J. Treatment timing for Twin-block therapy. Am J Orthod Dentofacial Orthop 2000;118;159-170.
34) Servello Jr, DF. Quantification of Skeletal and Dental Changes associated with the Forsus™ appliance: A Comparison of Treatment Effects Observed During and Following Peak Growth Velocity. Master's Thesis. April 2012.
35) Franchi L, Pavoni, C, Faltin K Jr, McNamara JA Jr, Cozz, P. Long-term skeletal and dental effects and treatment timing for functional appliances in Class II malocclusion. Angle Orthod 2013:83:334-340.
36) Pancherz H. The nature of Class II relapse after Herbst appliance treatment: A cephalometric long-term investigation. Am J Orthod Dentofacial Orthop 1991;100:220-233.
37) Freeman DC, McNamara JA Jr, Baccetti T, Franchi L, Frankel C. Long-term treatment effects of the FR-2 appliance of Frankel. Am J Orthod Dentofacial Orthopedics. 2009;135:570e1-570e6.
38) Kim, HY. Statistical notes for clinical researchers: Evaluation of measurement error 2: Dahlberg's error, Bland-Altman method, and Kappa coefficient. Restorative Dentistry and Endodontics 2013;38;3;182-185.
39) Springate, SD. The effect of sample size and bias on the reliability of estimates of error: a comparative study of Dahlberg's formula. European Journal of Orthodontics 2012;34;158-163.
40) Francisconi MF, Henriques JFC, Janson G, DeFreitas KMS, DosSantos PBD. Stability of Class II treatment with the Bionator followed by fixed appliances. J Appl Oral Sci 2013;21(6)547-553.
41) Malta LA, Baccetti T, Franchi L, Faltin Jr. K, McNamara Jr. JA. Long-Term Dentoskeletal Effects and Facial Profile Changes Induced by Bionator Therapy. Angle Orthodontist 2010;80;10-17.
42) Drage KJ, Hunt NP. Overjet relapse following functional appliance therapy. Br J Orthod. 1990;17:205-213.
43) Alvetro, Lisa. From "Plan B" to "Plan A": Using Forsus™ Class II Correctors as a Regular Mode of Treatment. Orthodontic Perspectives. 2007; Vol. XIV No. 2.
44) Yu SH, Nahm DS, Baek SH. Reliability of landmark identification on monitor-displayed lateral cephalometric images. Am J Orthod Dentofacial Orthop. 2008; 133:790 e1-6; discussion e1.
45) Kazandjian S[1], Kiliaridis S, Mavropoulos A. Validity and reliability of a new edge-based computerized method for identification of cephalometric landmarks. Angle Orthod. 2006 Jul;76(4):619-24.

46) Janson G, Caffer DDC, Henriques JFC, de Freitas MR, Neves, LS. Stability of Class II, Division 1 Treatment with Headgear-Activator combination followed by the Edgewise Appliance. Angle Orthod. 2004;74:594-604.

47) Miller RA, Tieu L, Flores-Mir C. Incisor inclination changes produced by two compliance-free Class II correction protocols for the treatment of mild to moderate Class II malocclusions. Angle Orthod. 2013 May;83(3):431-6.
48) Schudy FF. The Rotation Of The Mandible Resulting From Growth: Its Implications In Orthodontic. Angle Orthod. 1965 Jan;35:36-50.
49) Elms TN, Buschang PH, Alexander RG. Long term stability of Class II division 1 nonextraction cervical face bow therapy: Cephalometric analysis. Am J Orthod Dentofacial Orthop. 1996 Apr;109(4):386-92.
50) Drage KJ1, Hunt NP. Overjet relapse following functional appliance therapy. Br J Orthod. 1990 Aug;17(3):205-13.
51) Fidler BC, Artun J, Joondeph DR, Little RM. Long term stability of Angle Class II, division 1 malocclusions with successful occlusal results at end of active treatment. Am J Orthod Dentofacial Orthop. 1995 Mar;107(3):276-85.
52) Uhde MD, Sadowsky C, BeGole EA. Long term stability of dental relationships after orthodontic treatment. Angle Orthod. 1983;53:240-252.
53) Navarro Rde L, Oltramari-Navarro PV, Fernandes TM, Oliveira GF, Conti AC, Almeida MR, Almeida RR. Comparison of manual, digital and lateral CBCT cephalometric analyses. J Appl Oral Sci. 2013 Mar-Apr;21(2):167-76.
54) Richmond S, Shaw WC, O'Brien KD, Buchanan IB, Jones R, Stephens CD, Roberts CT, Andrews M. The development of the PAR Index (Peer Assessment Rating): reliability and validity. Eur J Orthod. 1992 Apr;14(2):125-39.